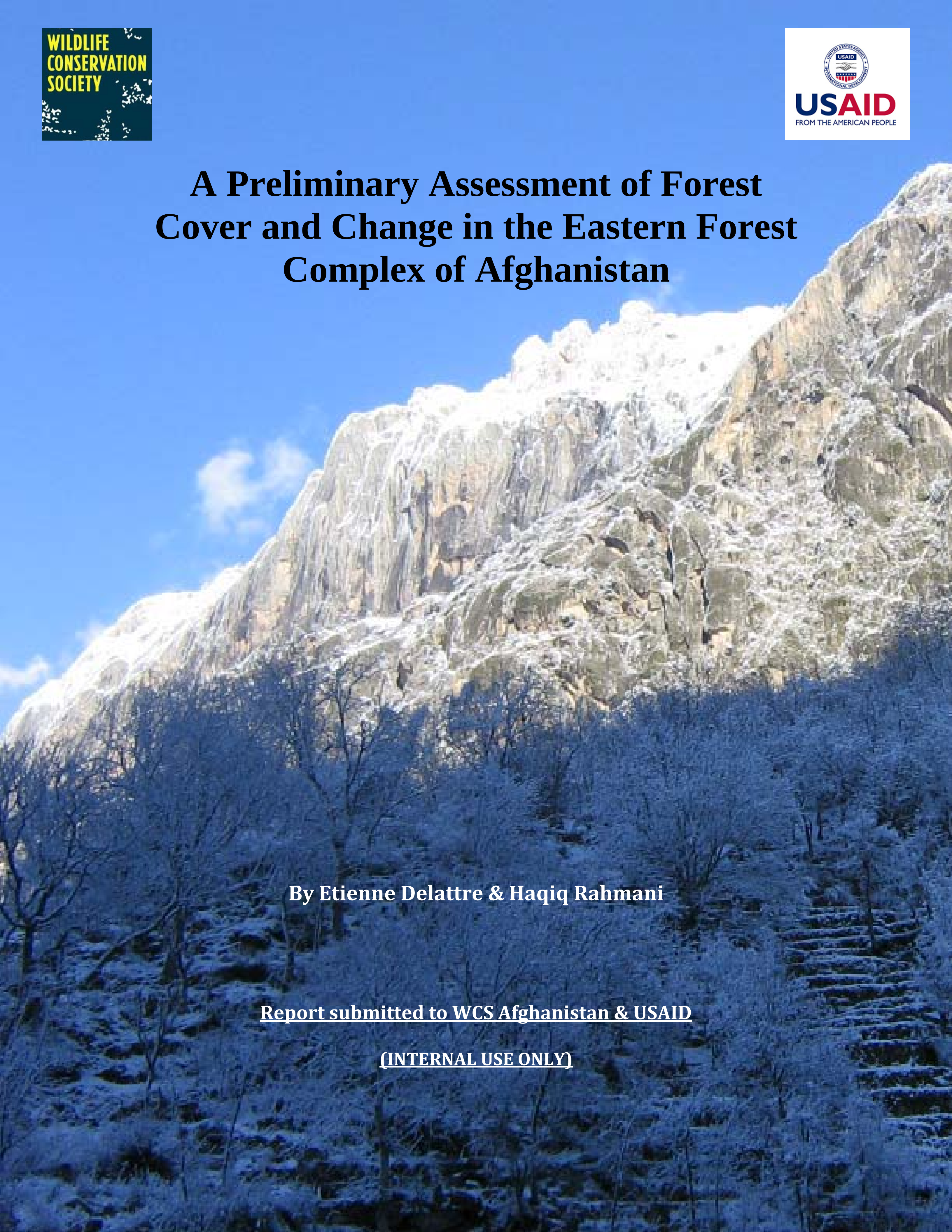

A Preliminary Assessment of Forest Cover and Change in the Eastern Forest Complex of Afghanistan

By Etienne Delattre & Haqiq Rahmani

Report submitted to WCS Afghanistan & USAID

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SUMMARY

The Eastern Forest Complex of Afghanistan constitutes the largest remaining forest complex in the country. It is made of a mosaic of habitats which includes the last contiguous patches of arid Conifers forests, and supports a biological diversity likely to be un-matched in the country, which justify to be singled out as one of the Global 2000 Ecoregions of the World. It is believed to be under serious logging pressure to supply growing in-country and cross-border timber trade. With the current instability and insecurity in that part of Afghanistan, the extent of this supposed forest plundering is unknown. A tentative assessment of forest loss and deforestation trend was undertaken by WCS using recent and affordable satellite imageries, applying innovative image analysis approach, and building capacities of designated personnel. Facing difficulties in the implementation of the analysis at various steps, some potential "deforestation hotspots" where forest loss may have occurred, have been detected and mapped. However, without any mean to go ground-truthing, there is not definitive certainty in the results obtained. Meanwhile, an updated forest cover (2007) could be derived from the deforestation exercise, for the area of interest covered in the analysis which represented more than half of the whole complex. Would further ground-checking in the field become an option, a renewed effort could be made to generate from the complete collection of recent imageries an updated forest cover for the entire Eastern Forest Complex.

ABBREVIATIONS

AoI	Area of Interest
Dtree	Decision Tree (algorithm)
EFC	Eastern Forest Complex
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information Systems
MLC	Maximum Likelihood Classifier (algorithm)
NDVI	Normalized Difference Vegetation Index
RS	Remote Sensing
UNEP	United Nations Environment Program
UNOSAT	United Nations Operational Satellite Applications
USAID	United States Agency for International Development
USGS	United States Geological Survey
WCS	Wildlife Conservation Society

INTRODUCTION

As part of a cooperative agreement with USAID, the Wildlife Conservation Society (WCS) has engaged itself into an ambitious and comprehensive program (2006-2009) aiming at preserving biological diversity in Afghanistan. This is seen as a contribution towards reconstruction and development in Afghanistan, through promoting an enhanced management of natural resources that most Afghan people depend upon. Different activities undertaken through this program falls into four broad categories: (1) baseline surveys and data analysis of wildlife and wild landscapes, (2) community-based initiatives, (3) strengthening of laws, policies and institutions, and (4) capacity-building of the environmental sector. Implementation is taking place in three major sites, namely (1) the Wakhan Corridor, (2) the Hazarajat Plateau and (3) the Eastern Forest Complex indeed.

In particular, the latter, hereafter abbreviated EFC, merits a special attention as it has truly become the last forested complex featuring substantial patches of arid Conifers forests in the Greater Himalaya. It benefits from the facts that precipitations are generally far higher and less erratic than anywhere else in the country. The forest complex could be as large a size as 13,000 sq km, spread across seven provinces, *i.e*. Nuristan, Kunar, Laghman, Nangarhar, Paktia, Khost and Paktika. It is mainly a rugged mountainous complex with its highest peak at *ca*. 5,700m. It is made of a mosaic of habitats, including different forest types, obviously highly dependant of the local topography (aspect, slope), oftentimes broadly defined as follow (EAST VIEW CARTOGRAPHIC 2003):

- agriculture (in basins, valleys) and barren lands, at elevations below *ca*. 1,300m;
- deciduous forests (Birch, Oak, Maple, Walnut), at elevations up to *ca*. 1,800m;
- mixed forests of deciduous and conifer patches, at elevations up to *ca*. 2,000m;
- conifer forests (Pine, Spruce, Cedar, Fir), at elevations up to *ca*. 2,500-3,000m;
- woodlands (Juniper), thickets, shrubs and grasses at elevations up to *ca*. 3,500m;
- alpine meadows and rocky placers, at elevations up to *ca*. 4,000m;
- snow, ice cap at elevations above *ca*. 4,000m.

This diversity boasts a whole suite of wildlife species of special interest, including historical populations of several species of Small Cats, Persian Leopard, Himalayan Lynx, Wolf, Stripped Hyena, Asiatic Black Bear, and several Ungulates such as Markhor, Urial, Siberian Ibex and Wild Boar. Through recent field surveys, WCS confirmed the presence of Canids (wolves, foxes, jackals), Asiatic Black Bear, Persian Leopard, and undifferentiated species of mountain Ungulates: Urial, Markhor and/or Ibex (WCS 2007c). The complex is an integral part of the Western Himalayan Temperate Forest, one of WWF's 2000 Ecoregions. It is assumed to be under tremendous pressure because of deforestation. Its positioning right along the Afghan-Pakistan border in a zone prone to conflict, its rugged terrain and long isolation, and its ethnic composition, make it an extremely challenging terrain to monitor biological diversity and threat to the landscape.


Conifer forest (© WCS)


Mixed patches (© WCS)

Deciduous forest (© WCS)

Agriculture (© WCS)

Asiatic Black Bear ***Ursus thibetanus*** (© WCS)

Golden Jackal ***Canis aureus*** (© WCS)

Himalayan Palm Civet *Paguma larvata* (© WCS)

Yellow-throated Marten ***Martes flavigula*** (© WCS)

Nonetheless, WCS Afghanistan's initiative in regard of studying, documenting and hopefully contributing to the preservation of the Eastern Forest Complex, is implemented through three main axis of intervention.

First, focusing on the remaining forests of Nuristan and Kunar provinces (so-called "the Study Site"), to conduct comprehensive wildlife surveys for determining species incidence for an area which has not been wildlife-surveyed for three decades. After hiring and training regional government counterparts together with local collaborators, multiple surveys across seasons were conducted in the rugged mountains, using both transect lines and camera-traps methods. A full report detailing techniques and findings has been published (WCS 2007c).

Secondly, in order to inform the perceived massive timber trade generated from the timber stock of the EFC, WCS also investigated current timber trade practices, also in a perspective of (re)drafting of adequate forestry legislation and policies. Most of the survey activities took place in timber markets of the Afghan capital Kabul. A full report detailing techniques and findings has been published (WCS 2008).

A third component of the EFC initiative, through the Afghanistan Program's GIS team, is a remote effort of collecting existing and appropriate remote sensing data to estimate forest loss over time, remaining forest cover, and determine adequate sample areas for wildlife surveys. Hence, this report contains both a presentation of what has been achieved in this respect, the EFC forest cover (and change) assessment, and a review of possible ways forward if this exercise is to be continued.
Indeed, what could be seen as an important but missing "piece of the puzzle", would be a spatially explicit representation of

- the current forest cover remaining in the EFC including the largest patches and linking corridors;
- the past-to-present patterns and trends in the loss of forest cover.

There is indeed this widespread perception in Afghanistan that the overall forest cover has been shrinking over the last decades. That is confusedly linked, first to the wide-ranging conflict which has ravaged the country for two decades; then, rather ironically, to the restoration of (relative) peace and stability in the country, and subsequent development. In particular, locals are often tempted to build a direct link between perceived deforestation in the Eastern provinces and the proximity of erstwhile rival Pakistan. UNOSAT, under the umbrella of UNEP's "Post-Conflict Assessment Afghanistan" effort, conducted a deforestation study which somehow confirmed this generally accepted view (UNEP/UNOSAT 2003). Unfortunately, given the absence of any comprehensive technical notes coming on top of the unavailability of the spatial datasets in digital format, such demonstration has seriously restricted itself to a limited scope and use. Moreover, while it supposedly documented massive deforestation and forest degradation over the decades of conflict, it leaves unanswered the question of the pace of forest cover change after the restoration of democratic institutions in Afghanistan post-2001. Hence, this current project aimed at providing further spatial information on the current situation of the forest cover in Eastern Afghanistan.

BACKGROUND

The most commonly used forest dataset available for the Eastern Forest Complex is the FAO's land cover dataset country-wide, based on a mosaic of Landsat 5 TM scenes (30 meters resolution) from year 1990 complemented with some scenes of 1993 (Fig. 1). This land cover dataset comprises three distinct "Natural Forests" classes generally accepted as forest types:

- Natural Forest - closed cover (> 60 % cover),
- Natural Forest - open cover (< 60 % cover),
- Degenerate Forest/High Shrubs (> 1.5m in height).

There is a comprehensive technical note attached to the dataset available (FAO 1999).

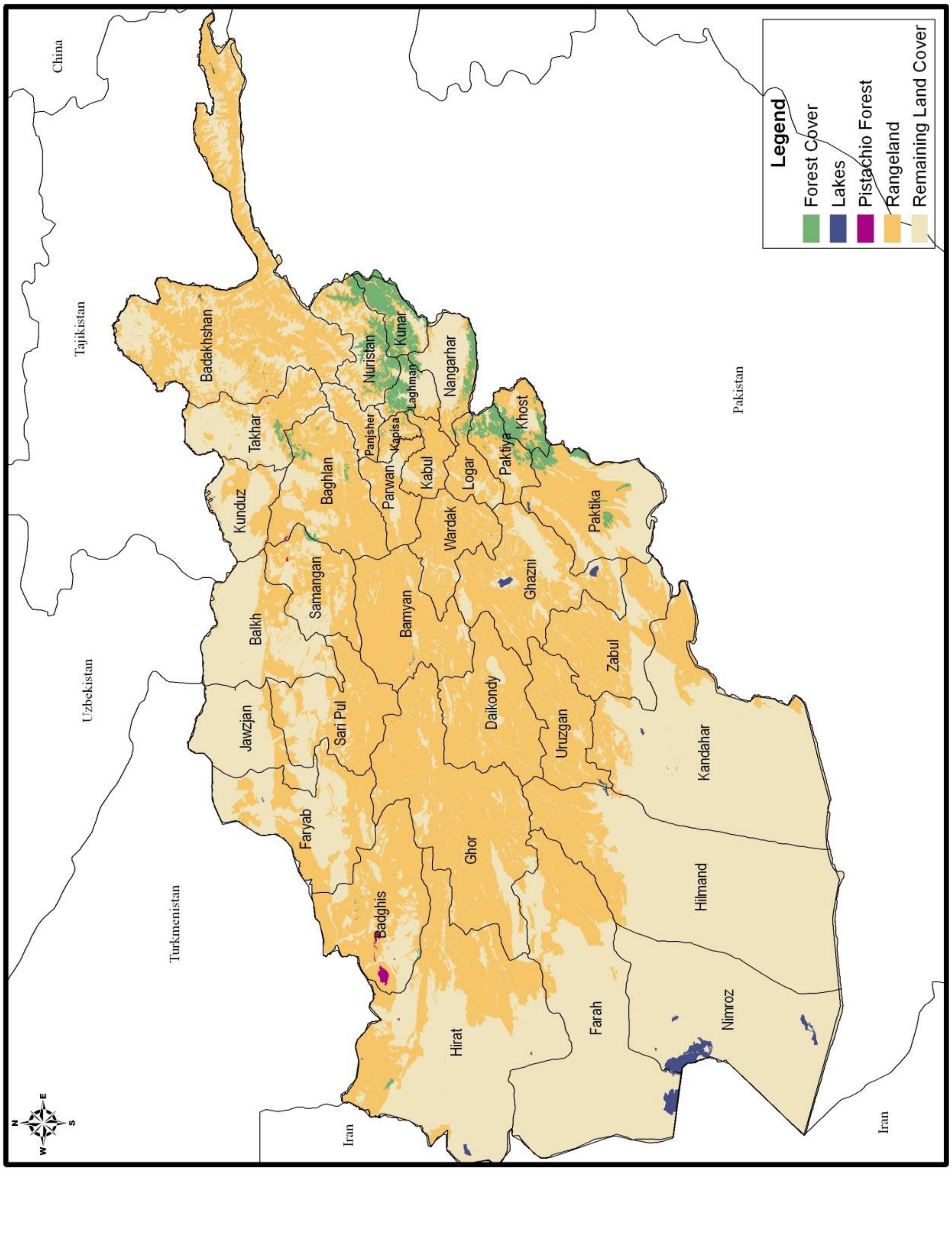
As mentioned, a decade later, an effort to update that forest cover while detecting and characterizing change in forest cover, was conducted by UNOSAT. A so-called "VEGETATION Image" of year 2001 based on a mosaic of Landsat 7 ETM was produced country-wide, updating the forest cover keeping the same three classes as in "FAO93" dataset. Meanwhile, spatial change between forest classes having occurred within this time period (1993-2001) was mapped out *(see Appendix 1)*. Furthermore, a separate effort to map change in forest cover and density between 1977 and 2002 was also undertaken for the three Eastern provinces of Nuristan, Kunar and Nangarhar, part of the EFC *(see Appendix 2)*.
Bizarrely, besides the fairly general and thin publication cited in References, there is no known technical note attached to comprehensively describe the methods used to get to these (supposedly) landmark results. Meanwhile, the datasets produced are only "available" on small scale, low resolution paper maps; it has been impossible to obtain any of these valuable spatial datasets in digital form, despite repeated efforts. That is unfortunate at least. A comprehensive technical note would have been an ideal baseline upon which we could have built and applied a similar method for analyzing more recent imageries and obtain an output to be seen as a valuable, comparative, updated product. The spatial datasets, in the mean time, would have been useful when displayed against the original scenes (that we have) and help inform us in our own decision-making – keeping in mind our lack of ground-truthing. Instead, we were left with developing an independent method of our own, and getting whatever results unconnected to the UNOSAT effort.

OBJECTIVES

The main objectives as described in the original project document, were "*to collect existing remote sensing data to estimate current rates of forest loss, classify remaining forest cover and assess remaining forest patches, and determine sample areas for wildlife surveys*" (WCS 2006).

The tasks as prescribed had been left (intentionally) vague. There was no time-series specified for the estimation of the current rate(s?) of forest loss. Incertitude also applies on how many and which classes should be considered.

Fig. 1 Map of forested areas in Afghanistan (FAO 1997)



As the Program started, this EFC project's objectives were tentatively refined. Based on preliminary findings of what imageries were available at a given cost, the ambition became, for the entire Eastern Forest Complex, to compare forest cover between the most recent available AND affordable imageries against the years 1970s, 1990s and 2000s, and compare forest loss and deforestation trends.

As the project progressed however, that set of objectives appears to be wishful thinking, taking into consideration a growing number of obstacles and difficulties, among them the complexity of the method, the restrictions in the availability and the limitations of the recent satellite images, the almost complete lack of crucial ground-truthing in a complex landscape. Those challenges were explained in full details in a Conceptual Note written late 2007 (WCS 2007a). That note outlined a possible way forward, ruling out a scientifically-sound and complex-wide full scale exercise, and suggested more a testing approach, while scaling down the objectives to the following set:

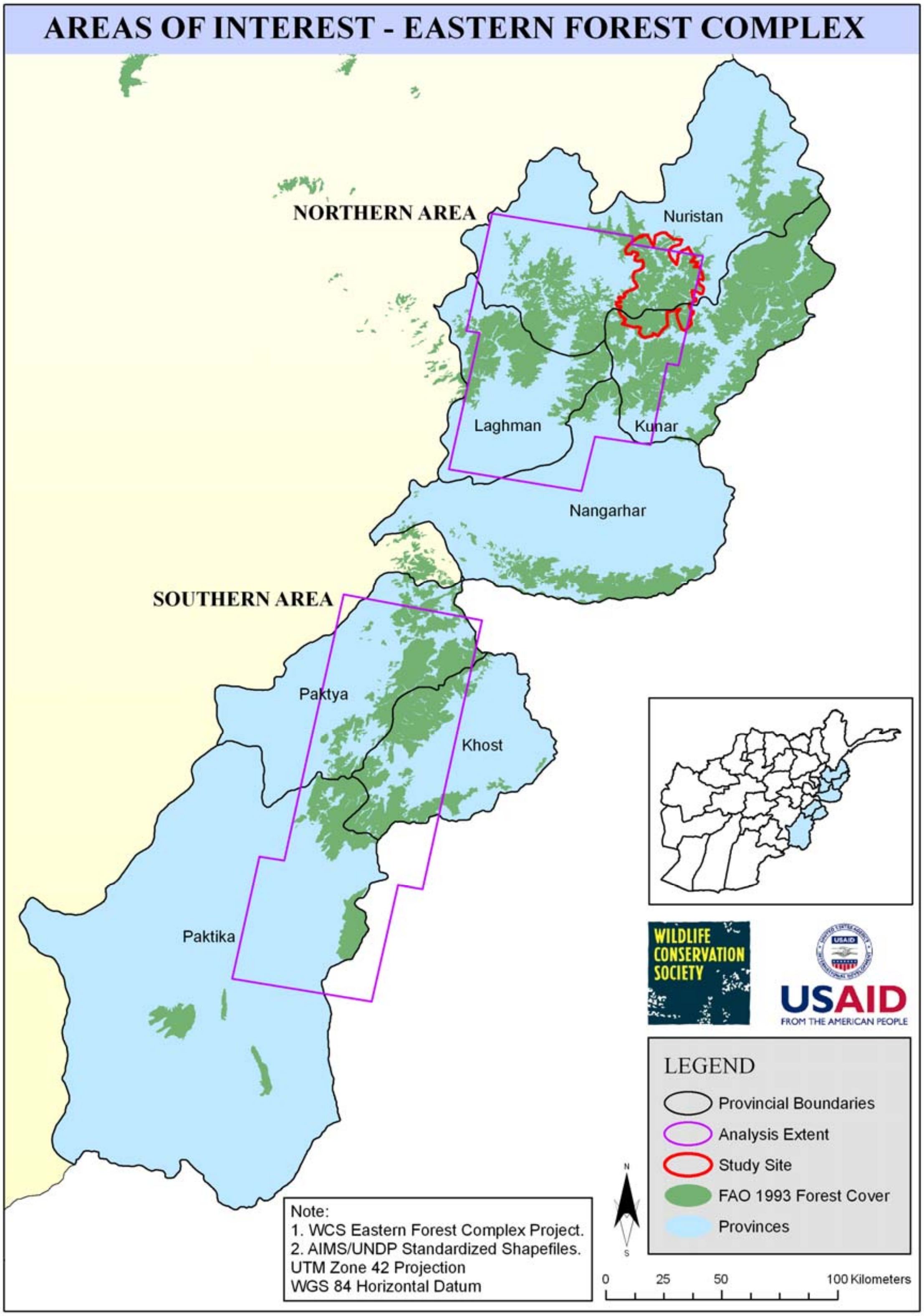
a) to train and build the capacity of key staff in conducting a full-scale forest cover change detection exercise;
b) to test a new approach in supervised classification, using the Dtree (Decision tree) algorithm, proved successful elsewhere;
c) to select and work on a smaller area, made of two distinct and representative subsets of the EFC, in order to obtain a spatially-explicit preliminary indication of what may have happened across the whole complex;
d) to conduct a forest cover detection exercise for these two subsets, comparing the most up-to-date imageries (2004-2007) against the equivalent imageries of respectively the 1970s, 1990s and 2000s;
e) if provable forest loss occurred over time-series, to identify spatial and temporal trends;
f) to derive where the largest forest patches still exist, and where are/were crucial forest (and likely, wildlife) corridors in between them linking the remaining key forest areas.

DEFINITIONS

Area of Interest

Initially, the exercise aimed at detecting change over-time in the forest cover of the entire Eastern Forest Complex. What exactly constitutes the Eastern Forest Complex is not set in stone. A widely accepted definition is that it would be made of all forested portions of seven provinces of Eastern Afghanistan, from the border of Badakshan in the northeast to the southern corner of Paktika in the southeast. As the project unfolded, and facing severe limitations in several aspects as hinted above, the spatial extent of the exercise was narrowed down to two distinct areas, still covering together a substantial proportion (greater than 50 %) of the whole forest complex (Fig. 2).

Fig. 2 Areas of Interest



Those two studied areas are respectively the so-called "Northern Area", centered on the Nuristan, Kunar, Laghman and Nangarhar provinces, covering 9,082 sq km; and the so-called "Southern Area", centered on the Paktia, Khost and Paktika provinces, covering 10,447 sq km. Both areas encompass *ca*. 7,000 sq km of the EFC forest patches as mapped in "FAO93", therefore our analysis covered well over 50 % of the total forested area of the EFC as classified by FAO (*ca*. 13,000 sq km).

Satellites

A collection of scenes from various satellite platforms and sensors has been gathered throughout year 2007. The collection consists in higher resolution data focused on Nuristan and Kunar provinces, medium resolution data scattered across the EFC, and lower resolution data for the entire complex.

Data are from the following platforms/sensors:

- Landsat MSS, V-NIR bands, 80 m resolution, 1972-1979
- Landsat TM, V-IR bands, 30 m resolution, 1989-1992
- Landsat ETM, V-IR bands, 30 m resolution, 2000-2002
- Aster, V-IR bands, 15/30 m resolution, 2004-2007
- Spot 4/5, V-IR bands, 10/20 m resolution, 2004-2006

Coverages

The respective areas covered by each satellite platform/sensor are successively listed below and displayed in the attached figures.

1. <u>Coverage 1: Spot 4/5 2004-2006</u>

These 10 scenes (*ca.* 60 x 60 km each) mosaicked altogether cover the entire UNOSAT area *(see Appendix 3a)*. They were specifically ordered for the EFC Project through a French provider OBSCOM.

<u>Advantage</u>

Those scenes constitute the most up-to-date package of scenes available for the core area in question, at the highest affordable resolution (10-20m). A subsequent, additional two Spot 5 scenes were graciously given for free in summer 2007.

<u>Drawback</u>

Due to technical problems of geo-referencing in such mountainous terrain, said to be inherent to Spot platform, the position accuracy was far less than satisfactory. There was a random offset throughout the mosaic, ranging from “none” to up to 250+ meters in the worst case (typically, the NE zone). Hence, as it stood, the entire mosaic was unusable for the purpose of forest change detection. Some scenes were acceptable and could still be exploited individually, while attempts are yet to be made to try manually to salvage the most problematic ones.

2. Coverage 2: Aster 2004-2007

This assemblage of 32 scenes (*ca.* 60 x 60 km each) together covers the entire Eastern Forest Complex *(see Appendix 3b)*. They were ordered through the Japanese provider of Aster products.

Advantage

This set of scenes contained up-to-date scenes (summer 2007) for part of the area in question, at a nice resolution (15-30m). They were also somewhat easier to use and interpret. It is always possible that newer additions will come up and that needs to be checked.

Drawback

The range between dates (2002-2007) and the scene's small size (60 x 60 km) made the whole series problematic to be considered and handled as one single, mosaicked set for the entire EFC.

3. Coverage 3: Landsat ETM 2000-2002

This assemblage of 7 scenes (*ca.* 180 x 180 km each) together covers the entire Eastern Forest Complex *(see Appendix 3c)*. They were obtained for free through the GLCF-Maryland data provider facility (with one additional scene from USGS Afghanistan data provider).

Advantage

Although of medium resolution (30 m), Landsat has always been considered as the best cost-effective product to conduct a land cover classification/change detection exercise. They are the easiest to use and read. As it stands, it is the best set to be used as a reference against which others may be compared. It is typically the set used by UNEP.

Drawback

Sadly, the service has been discontinued due to technical problems in Landsat 7 since July 2003. Any correction since then still does not make this platform a valid option as baseline data for land cover change detection.

4. Coverage 4: Landsat TM 1989-1992

This assemblage of 7 scenes (*ca.* 180 x 180 km each) togethe covers the entire Eastern Forest Complex *(see Appendix 3d)*. They were obtained for free through the GLCF-Maryland data provider facility.

Advantage

Although of medium resolution (30 m), Landsat has always been considered as the best cost-effective product to conduct a land cover classification/change detection exercise. They are the easiest to use and read. It is typically the set used by FAO.

Drawback

It represented rather a ‘mid-way’ set for any time comparison, making it possibly less interesting. Sadly, it is no longer possible to obtain recent Landsat TM data for Afghanistan.

5. Coverage 5: Landsat MSS 1972-1979

This assemblage of 5 scenes (*ca.* 180 x 180 km each) together covers the entire Eastern Forest Complex *(see Appendix 3e)*. They were obtained for free through the GLCF-Maryland data provider facility.

Advantage

Although of lower resolution (57 m), it is still a Landsat product which offers the easiest way to conduct a land cover classification/change detection exercise at large scale. Moreover, this series represented the oldest set of images which anything else could be compared with.

Drawback

It has the lowest resolution (57 m) and the least number of available bands (excluding IR), which makes any comparison with subsequent imageries, including with its own namesake Landsat (5 TM, 7 ETM+), far more challenging.

METHOD

The following describes the method used to generate and validate the outputs.

Time series satellite data

In order to fulfill our general objective of detecting forest cover change across the EFC over 3 different time periods, we built a comprehensive collection of imageries, for four time periods (1970s, 1990s, 2000s, 2004-2007) from different satellite image sensors/platforms - as described above with each one's advantages and drawbacks. The baseline imagery adopted was a selected set of recent Aster scenes (2004-2007), against which older Landsat imageries of the 1970s, 1990s and 2000s would be compared to. As we moved on from covering the entire EFC to two distinct, representative subsets, one in the northern half of the complex and one in the southern half of the complex, we opted to base our work on an Aster scene size, which is 60x60 km. Indeed, as we had shifted towards a 'testing mode' approach, we wanted to maximize our chance by treating the selected baseline imageries (the Aster scenes) individually, in order to retain each one's own quality and seeking to get what would be potentially the best outputs, instead of going through an inevitably downgrading mosaicking/resampling process.

Hence, the Aster scenes extents (A*i*) below were covered by the following dates:

	ASTER	LANDSAT 7	LANDSAT 5	LANDSAT 3
A4	18/07/2007	18/10/2000	09/06/1990	28/09/1972
A12	15/10/2007	05/10/2001	09/06/1990	20/06/1979
A22	23/11/2007	05/10/2001	09/06/1990	16/10/1979
A23	07/11/2007	18/10/2001	09/06/1990	28/09/1972
A24	07/11/2007	18/10/2000	09/06/1990	28/09/1972
A26	26/08/2004	05/10/2001	09/06/1990	-
A31	11/09/2004	05/10/2001	09/06/1990	20/06/1979

Some scenes presented limited cloud cover, which had to be removed for the deforestation analysis. To construct an updated, refined forest cover as a by-product (as described later), any area covered by cloud in any of the 3 Landsat scenes was analyzed based on what appeared to be on the ground in the surroundings + on that spot on either of the two remaining (cloud-free) Landsat scenes. In one critical instance (core area of Nuristan) where some clouds were present on Aster (A26) with evident portions of Forest surrounding and likely underneath (based on Landsat), those patches were checked on the "FAO93" cover, and indeed re-classified as Forest if that was true.

Image classification method

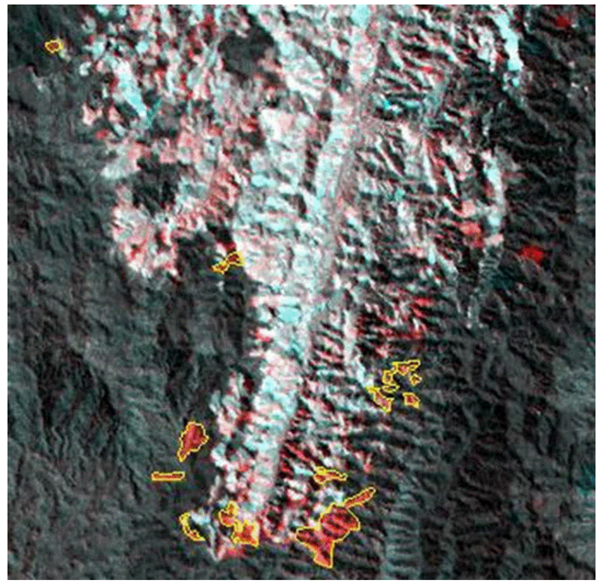
Besides re-formulating the project's objectives and identifying, assessing, selecting and ordering the series of satellite imageries for the three time periods, another substantial effort was put in searching and formulating an appropriate image analysis method for this forest cover change detection. An extensive effort of literature review and consultation took place.
To conduct a land cover change, there are several possible approaches, each with its own strengths and weaknesses. It is not intended here to provide an extensive review of all change detection methods, which could number in dozens with variations. However, we did consider the most common approaches, as outlined below, before adopting one and designing a classification method around it.

Comparing two classified images, or **post-classification**, where two land cover datasets are produced by classifying separately the images of each date followed by a comparison of these land cover outputs to determine land cover change, is probably the most intuitive method.

Source: AMNH 2006b

However, it rarely produces the best results (AMNH 2006a,b), and is rarely recommended. Indeed, the errors when classifying each image are cumulative and incorporated into the final land cover change dataset, often degrading its quality to a level below the acceptable standard (typically, > 80 % accuracy) while the constituting datasets may still score well (e.g. 80 % for early date and 80 % for late date BUT 64 % for the combined dates). Given the expected difficulties in classifying images of this rugged landscape and the complete lack of field data points (for training sites and accuracy assessment), using this approach was quickly ruled out.

By contrast, **on-screen digitizing** is a manual method to create land cover and land change maps, relying only on visual interpretation and drawing on screen. It is arguably the most subjective of all approaches, which has its pros and cons. A human brain well fed by knowledge of the landscape, is oftentimes better at analyzing and separating features than the computer (AMNH-CBC 2007). However it is highly prone to bias linked to the operator, more so than any automated method.



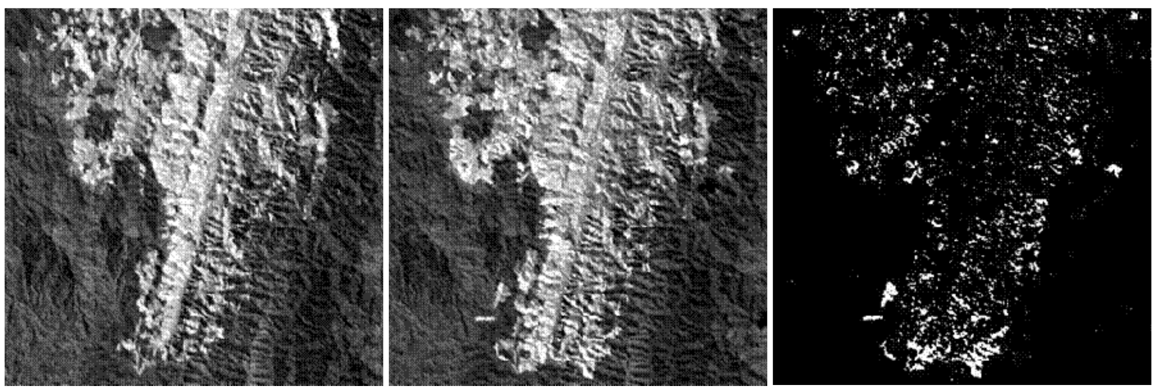
Source: AMNH 2006b

In particular for this land change detection exercise, such visual interpretation was seriously considered: to perform a manual editing of the only existing land cover dataset of reference (the "FAO93" dataset) through the different time-series, up and down the time scale. A variation of that method, called **hybrid approach**, would have been to use an automated method of our choice to come up with a draft classified land cover dataset of our own, then visualize it on screen and start editing it manually through the time-series. Once (and by far) the preferred method, testing it with the GIS/RS Analyst here did not prove convincing in the context of our landscape, arguably given both its mountainous terrain and the peculiar forest types. While in many instances the operator agreed with the outlines of the forest patches in "FAO93" when displayed against the source imagery (1990s), he felt lacking of confidence when having to draw his own forest patches limits on that scene after toggling off "FAO93", or in editing those "FAO93" patches when displayed against another time scene. The feeling of subjectivity and uncertainty was at its highest; given the expressed wish to get into a more objective and automated approach, the on-screen digitizing method was discarded.

Using an **image math** approach was another option considered. This approach works through comparing individual or single bands of two separate dates and computing difference between them.

Source: AMNH 2006b

It is often applied through the use of vegetation indices such as Normalized Difference Vegetation Index (**NDVI**), among others. NDVI images are subtracted one from another and the resulting output is analyzed with a set range of values identified which theoretically could represent a change in land cover between the two dates.

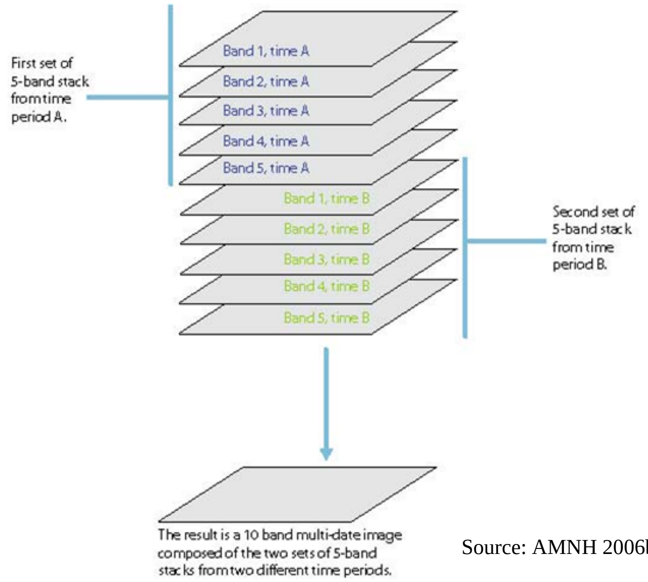


Source: AMNH 2006b

It is presumably the method applied in UNOSAT analysis, believed to have applied it on half a dozen of SpotVegetation images (res. 1 km) spanning across all seasons (UNEP-UNOSAT 2003).

While supposedly an easier and faster method, we were not acquainted enough with NDVI to take the risk of choosing it as the method of choice. However, we did a test by simple subtraction of band between two images (Red = single band of late date, while Green, Blue = same or similar band of early date) did not give us convincing results. Moreover, if any, it would only deliver a dataset of change without specifying what change and without the possibility of getting an updated forest cover dataset of some sort. Finally, a serious drawback of this method is that it is said to be quite sensitive to variations unrelated to real land cover change on the ground but rather coming from atmospheric conditions (clouds, haze) and seasonality (AMNH 2006a). Considering the facts that we were in the impossibility to apply any radiometric corrections between images/sensors; that clouds, snow and haze were present in proportion throughout the whole set of images (as said above); and that a seasonality effect would likely occur given the wide-ranging variations in dates of our scenes collection (from June to November, as above); it was decided not to investigate this approach any further.

When using the **multi-date composite classification** approach, images from two dates are combined into one multi-temporal image. This single image is then classified using the automated classification method and algorithm of choice, for which the "layer-stacked" image is used as input into the classification.



Source: AMNH 2006b

This approach has the advantage of directly outputting change classes, reducing the classification error compared to the post-classification approach described above. As a consequence though, this method does not directly output land cover maps for each individual dates; however, information in this regard can be derived from the change classes, as by-products. The limitations of this method are similar to those associated with automated classification in general. Depending on the quality of the two images combined into one, there may be variations across one or both images that is not related to changes in land cover, and this variation would make it difficult to consistently identify change with reasonable accuracy.
Still, that approach had been tested and used elsewhere with apparent success, comprehensive documentation, and subsequent training (WCS/CI-CABS 2007). If the automated route was to be taken, it is often the method of choice. In the meantime, all other approaches above had been discarded for this specific exercise, as explained. Therefore we decided to go for it and to develop a method around it.

Once the multi-date composite classification approach became the method of choice, the next decision to be made was which algorithm to use. Similar to the range of change detection methods, there are more than a few algorithms to choose from. Here too a literature review was made, and the pros and cons of the major ones tentatively identified and listed. That proved to fly far beyond the scope of this exercise, with highly specific and debatable experiments, less-than-firm conclusions and open-ended questions left to the realm of so-called remote-sensing experts. Needless to say that all of those experiments took place for areas of interest nowhere near looking like our landscape.
The tendency would have been to adopt the Maximum Likelihood Classifier (MLC), one of the most commonly used algorithm in supervised classification. However, another way of classifying using Decision Trees (Dtree) has emerged as a new approach, tested elsewhere and producing more accurate classifications than the MLC, with convincing statements, applications and documentations (CI-CABS 2006, *see Appendix 4*). That has been fully developed into a ready-to-use technique with set steps, that we decide to take

on and apply (with adaptation), also in a spirit of innovation and training-capacity building. The Dtree-based classification algorithm in question was chosen, after having been trained by a researcher of the Conservation International's Center for Applied Biodiversity Science. A strict scientifically-sound approach would have commanded us to compare outputs from Dtree and MLC algorithms in this specific EFC landscape context first, given that method had been applied in tropical settings only, and it is not known how it would fare in areas of haze and/or of high topographic complexity, in terms of (mis)classification. However, any rigorous effort in this regard would have been vain given our complete lack of a decent set of field data points across the complex, which should have been used for assessing the accuracy of both outputs, in order to either validate or infirm our choice of algorithm.

We however still wanted to conduct such test for one scene (A12), running a supervised classification following obviously same or similar steps:
- made of same number of iterations,
- using same (in number and position) and similar (in size) training sites (for MLC, smaller and more homogenous than for Dtree, as recommended),
- featuring the same classes (in number and definition).

The result displayed on screen was visually checked. While to our surprise Dtree seemed to increase rather than decrease the so-called "salt-and-pepper" effect (scattered clumps of pixels) compared to MLC, we found that it "translated" better, in a much finer aspect, the topographical complexity and therefore vegetation pattern of the landscape, visually more apparent on Dtree output than on MLC output where all features seemed "flattened". Fig. 3 shows the respective results for an area of complex topography. Although not rigorous, while knowing that we would have to remove that "salt-and-pepper" effect through post-processing steps (by filtering, cleaning, editing) either way, we decided to stick to our choice of algorithm, Dtree.

Fig. 3 Visual comparison between MLC and Dtree classifier

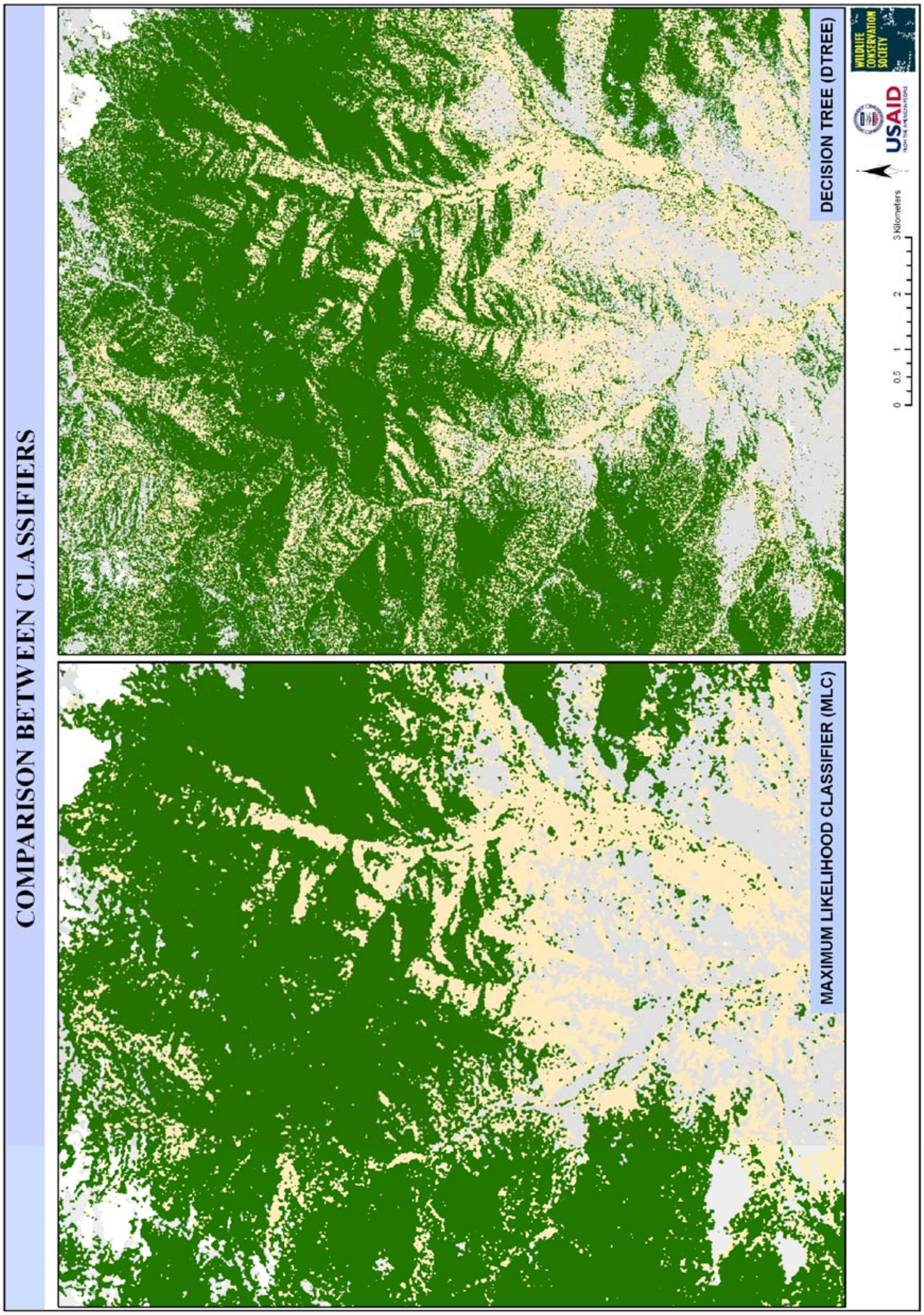


Image processing

A series of image processing tasks ahead of the forest cover change detection exercise, included (where appropriate)

- resampling to the highest resolution considered (Aster, 15 meters),
- subsetting to the baseline image extent (Aster, 60x60 km),
- reprojecting to suitable projection (UTM zone 42 N),
- co-registrating (adjustment of each scene geo-position to less than 1 pixel size),
- stacking adequate time-series layers (15 bands for Aster vs. Landsat 7,5 and 13 bands for Aster vs. Landsat 3),
- displaying appropriate bands combination (RGB 4-5-3 for Landsat 7,5 and RGB 3-4-2 for Aster, Landsat 3),
- enhancing image through brightness/contrast (Standard Deviation 2.0),

Typically for a forest change detection, radiometric variations between scenes may be important to address, while geometric corrections are essential. As hinted above, radiometric correction to neutralize atmospheric effects on different scenes was out of question: we had neither the skills and capacities, nor the necessary information (metadata) to be able to address that potential source of error, likely to be present given the various platforms in question. Meanwhile, an emphasis was put on the crucial geometric corrections, *i.e.* to have the scenes lined up in the best possible fashion. This co-registration proved to be difficult, given the spectacularly mountainous terrain, especially between different platforms (Aster vs. Landsat) and even sensors (Landsat 3 vs. Landsat 5,7). In some instances, despite considerable efforts, the rule of one pixel size (15 m) offset maximum for land cover change detection, could not be enforced throughout a given scene extent, with however a root mean square error (RMSE) never exceeding 30-50 m.

Definitions

We purposefully limited our classes to a small number. We defined "Deforestation" as the removal of trees. We defined a "Forest" class as non-modified forested areas (without separation in sub-classes based on canopy cover percentage). We defined "Barren" class as areas without native trees. We defined "Agriculture" class as human-affected areas where settlements, tree plantations and orchards, cereals fields and vegetables crops are present. In few instances, water bodies were present, labeled as "Water".

Image classification strategy

Once the automated method and the algorithm adopted, and the image processing steps accomplished, we were in presence of three layer-stacked images for each of the seven Aster scene extents, combining the latest Aster image (2004-2007) with respectively the Landsat 7 ETM+ (2000s), Landsat 5 TM (1990s) and Landsat 3 MSS (1970s) images.

The choice was made to start classifying each series with the shortest time-difference, in full Aster-Landsat 7; then followed by Aster-Landsat 5, then Aster-Landsat 3. We

identified training sites (= homogeneous areas) for forest, non-forest (barren) and agriculture areas by visually analyzing on screen the reflection of sunlight from the Earth's surface in three spectral regions (displayed in Blue-Red-Green combination): red, near infrared, and short-wave infrared, corresponding to Bands 2, 3 and 4 for the Aster data, and Bands 3, 4 and 5 for the Landsat 7 & 5 data (as Landsat 3 do not have full infra-red, we were forced to use visible and near-IR bands # 2,3,4 instead). The red and infrared bands are the most commonly used bands for land cover purpose, as they are less affected by the atmosphere than the blue and green bands, and therefore produce higher visible contrast, *e.g.* between forest and non-forest.
Those training sites were entered with respective spectral signature and sub-classes attribute into that Dtree-based classification algorithm, to generate a classification of the Aster-Landsat 7 scene into 'change' classes and 'non-change' classes.

Change classes were:
(a) Forest in ~2000 and Non-Forest in ~2007 (= deforestation)
(b) Cloud in ~2000 and Forest in ~2007
(c) Cloud Shadow in ~2000 and Forest in ~2007
(d) Cloud in ~2000 and Barren in ~2007
(e) Cloud Shadow in ~2000 and Barren in ~2007
(f) Cloud in ~2000 and Cloud Shadow in ~2007
(g) Cloud Shadow in ~2000 and Cloud in ~2007

Non Change classes were:
(A) Forest in ~2000 and Forest in ~2007 (= remaining forest cover in 2007)
(B) Barren in ~2000 and Barren in ~2007
(C) Agriculture in ~2000and Agriculture in ~2007
(D) Water in ~2000 and Water in ~2007 (lakes, reservoirs, largest rivers)
(E) Cloud in ~2000 and Cloud ~2007
(F) Cloud Shadow in ~2000 and Cloud Shadow in ~2007

It appears that one major 'change' class is missing: Non-Forest in ~2000 and Forest in ~2007 (= regrowth). They were reasons for that. First and foremost, the focus of the exercise was to document and validate a generally accepted perception of deforestation trend over time;. They are virtually no accounts of any (re)growing forested area, that with all difficulties and uncertainties this exercise was facing, we did not wish to spend additional time checking that very hypothetical, reversed trend. Ecologically in the meantime, our classes as defined leave very little room for that phenomenon to happen and be detected: the natural forests of this landscape would certainly never "re-grow" (?) on agriculture soil (doubtfully assuming they were ever present in those lowland, cultivated areas); while it is also difficult to imagine in this biological and human landscape, a land having assumingly been stripped of its forest and left barren, then seeing the forest claiming it back. At best, one could think of some instances of forest 'regeneration' rather than forest 'reclaim', but the problematic of change in forest structure (degradation >< regeneration) was never to be addressed in this exercise, as we believed it was technically impossible to measure it through satellite image analysis alone.

In addition to entering training sites for each of the classes above into a signature file (Erdas), those Aster-Landsat 7 training sites (with class attributes) were systematically converted into a spatial dataset format (ArcGIS), to be re-imported onto the Aster-Landsat 5 stacked image, then again onto the Aster-Landsat 3 stacked image. Each and every training site was visually reviewed on screen in a similar fashion as above, and decision made to either keep, edit (in shape or attribute), or delete it (in few instances); in some cases, additional training sites were added. Proceeding this way, we aimed to limit the risks inherent in making dual, independent classifications (similar to the issues in post-classification method as described above), by consistently re-using the same set of training sites (with revision). In particular, and quite obviously, if any change in classes between the time-series was apparent, it was carefully and consistently considered, following common sense and likelihood of Forest-Deforestation trend over time. That logic is graphically displayed below.

2004/2007	**2000s**	**1990s**	**1970s**
Forest	Forest	Forest	Forest
Non-Forest	Non-Forest	Non-Forest	
Agriculture	Agriculture	Agriculture	Agriculture
Barren	Barren	Barren	Barren

For each time-series several iterations were run to correct obvious misclassifications. Once the output seemed to be acceptable, we went into a phase of post-processing it.

Data post-processing

Each classification result went through a series of post-processing steps, in order to refine the output and eliminate some of the so-called "salt-and-pepper" effect. Two filtering steps were applied: (1) 2 times 3x3 Statistical Filtering (Majority) built-in ERDAS and (2) one Generalization Majority filtering using Spatial Analyst extension in ArcGIS. In addition, remaining scattered clumps of "Forest" pixels surrounded by "Barren" or "Agriculture" areas AND lying outside the maximum extent of "Forest" in the land cover dataset of reference "FAO93", were reassigned as "Non-Forest" together with the "Barren" and "Agriculture" pixels after recoding, in order to further smoothen the classification output.

Accuracy assessment

Quite dramatically, the project as designed, never encompassed the crucial problematic of accuracy assessment, which could only validate (hopefully) any of its findings regarding spatial and temporal trends in deforestation. As a matter of fact, there was no reference information available to validate the accuracies in our class assignments for the -2000s, -1990s and -1970s imageries. For obvious reasons, no field surveys were undertaken or, if any, the results never published. As for the -2007s imageries, there could have been a possibility of collecting dedicated field points in order to validate our class assignment for the Aster 2004-2007 scenes. However, for multiple reasons (lack of human resources, lack of specific funding, vastness of the area, remoteness and ruggedness of the terrain, increased insecurity due to insurgency and banditry…), that unfortunately did not take place. As an alternative, selected high resolution satellite imageries (e.g. Ikonos, QuickBird) or aerial photos taken at similar times and scattered across the complex, could have done the trick. However we have never been aware of the existence of any such product, while it was unthinkable to invest further effort and funds in trying to acquire recent and costly products of that sort.

We have however been keen to go through the step of accuracy assessment, for indicative and training purposes if nothing else, by exploiting the little we had, in this case a set of field data points collected by the Nuristan Wildlife Teams when surveying wildlife in the so-called Central Nuristan Wildlife Survey Team Study Site. That set of points, a product of surveys not focused on forest cover and change, could only be used in a fairly limited fashion, to calculate the accuracy of a by-product, a forest cover dataset 2007 for a restricted area. All GPS points were compiled together to create an *ad hoc* set of points for accuracy assessment. Points with attribute "Non-Forest" had to be discarded, as seemingly they were oftentimes collected in small openings such as on roads, therefore un-detectable on the imageries. As for the "Forest" points, the initial intention was to separate into defined forest types, mainly "Oak" and "Conifers" sub-classes. However, that was not well implemented on the ground; a number of points did have attribute with multiple forest types checked at one location, which throw into question the meticulousness in forest type identification. This somewhat weakened further the strength of this point dataset, which was never dedicated to accuracy assessment in the first place. Still, it featured a not negligible sum of > 1,500 "Forest" points, which were used to inform us on the overall accuracy of a single forest classification output.

Capacity building

The EFC forest cover and change exercise was developed with the full and active participation, in each and every steps, of the WCS Afghanistan GIS/RS Analyst, Mr. Haqiq Rahmani, a talented GIS operator although with limited knowledge of forestry and remote sensing at the start.

The bulk of the year 2006 was focused on getting a functional GIS unit off the ground, spatially serving all components of the Program in field, analysis and reporting activities. In the meantime, the GIS Analyst was closely exposed to and trained in aspects of GIS applied for wildlife conservation and management, through regular visits by WCS Asia GIS/Landscape Analyst Mr. Etienne Delattre.

The year 2007 got him exposed to the basics of remote sensing and applications for conservation. It was done through a 2-folds approach:

1. externally, through a two-weeks long training (April 2007) provided by the Smithsonian Institute, Washington DC, in a course on "GIS/RS in Conservation and Wildlife Management", which included modules on "Land Cover Change and Endangered Species";
2. internally, through the continued visits by Mr. Delattre, where hands-on training, assignment and supervision of the GIS Analyst in the application of the approach took place.

The GIS Analyst took an important role in all steps above, prior to the images classification. By year's end, the source imageries were all ready, the method designed and tested, and the training provided.

This year 2008 saw him conducting the bulk of the image interpretation and post-processing efforts, while contributing to the analysis and subsequent reporting.

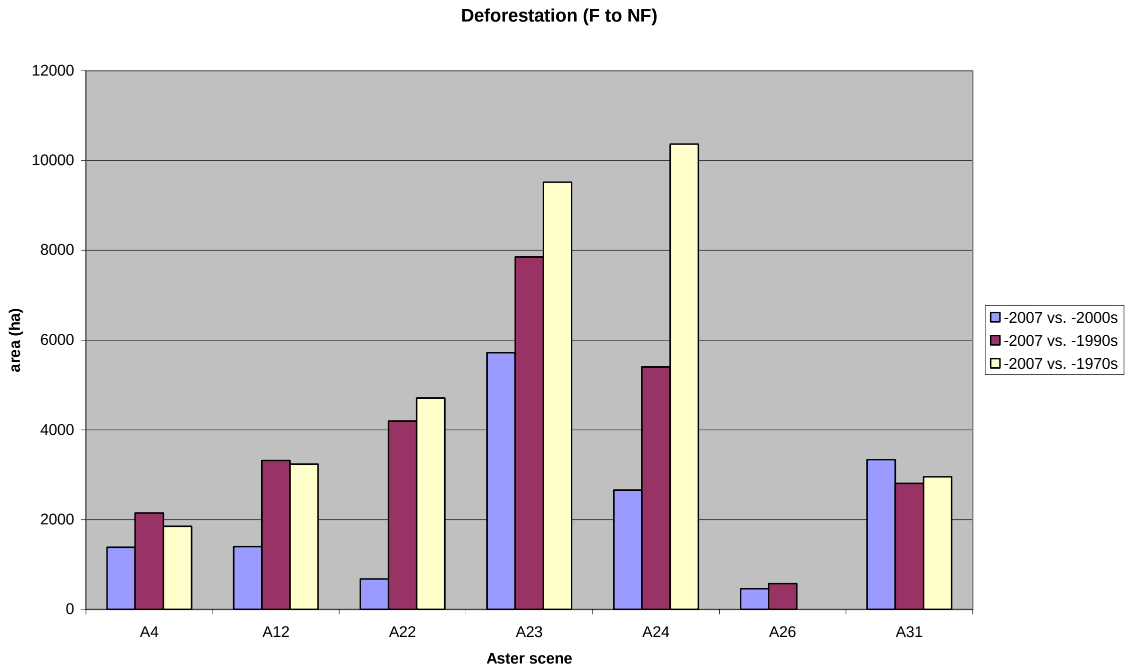
RESULTS

Deforestation

As a result of the method, visually detecting training sites supposedly "Non-Forest" on the recent Aster scene (-2007s) against the same site supposedly "Forest" in any of the previous time-series considered (-2000s, -1990s, -1970s), we obtained for each scene three supervised classification outputs featuring pixels, clumped and patched to depict "F to NF class" areas, where deforestation may potentially have occurred. Working on individual Aster scene independently, from the shortest time-difference to the longest time-difference, we obtained the following results.

Aster #	Deforestation (ha)		
	2007 vs. 2000s	2007 vs. 1990s	2007 vs. 1970s
A4	1384	2146	1853
A12	1402	3321	3236
A22	681	4198	4709
A23	5720	7850	9514
A24	2656	5398	10365
A26	458	574	-
A31	3338	2808	2954

These area figures are represented in the chart below.



In most instances, it "nicely" (or rather, logically) shows an increase in forest loss as we compare the deforestation over time-series, backward. It also tends to show that the bulk of the deforestation is featured for those scenes (A23, A24) located in the southern half of the EFC, less mountainous and more accessible, also located closer to Pakistan.

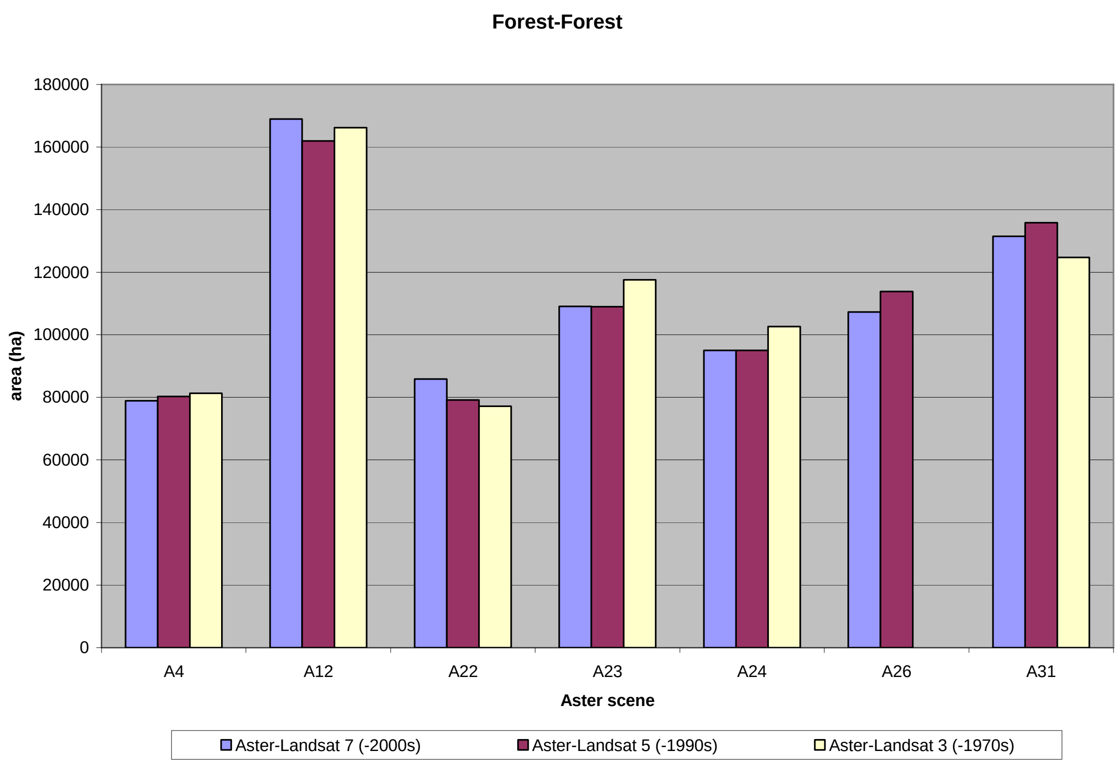
The next steps would have been (1) to try to relate these figures to forest cover areas, as to calculate a series of percentages of forest loss; (2) while also to make comparison between time-series, in order to detect trends over-time. Starting with the former, the method however does **not** yield any immediate information on forest cover at the earliest date of each time-series. In the absence of any reliable source of information, calculating a percentage of forest loss over time for each time-series is therefore not possible. One could be tempted to exploit each scene's three different forest cover outputs and manipulate the 'forest' and 'non-forest' classes in between those to try to deduct this missing information of not knowing the forest cover area at the earliest dates. However that would be a misguided move, given that each map output is **not** a land cover dataset *per se* (featuring F, NF…), but rather a land change dataset (featuring F-F, F-NF, NF-NF…). Theoretically, for each scene and each time-series, one could add the F-F areas with the F-Def areas, and calculate a percentage of forest loss compared to that sum. However, that route is not to be taken here, as the examination of further results that could be derived, *i.e.* updated forest cover areas, highlighted the limitations of the results we obtained altogether.

Forest cover

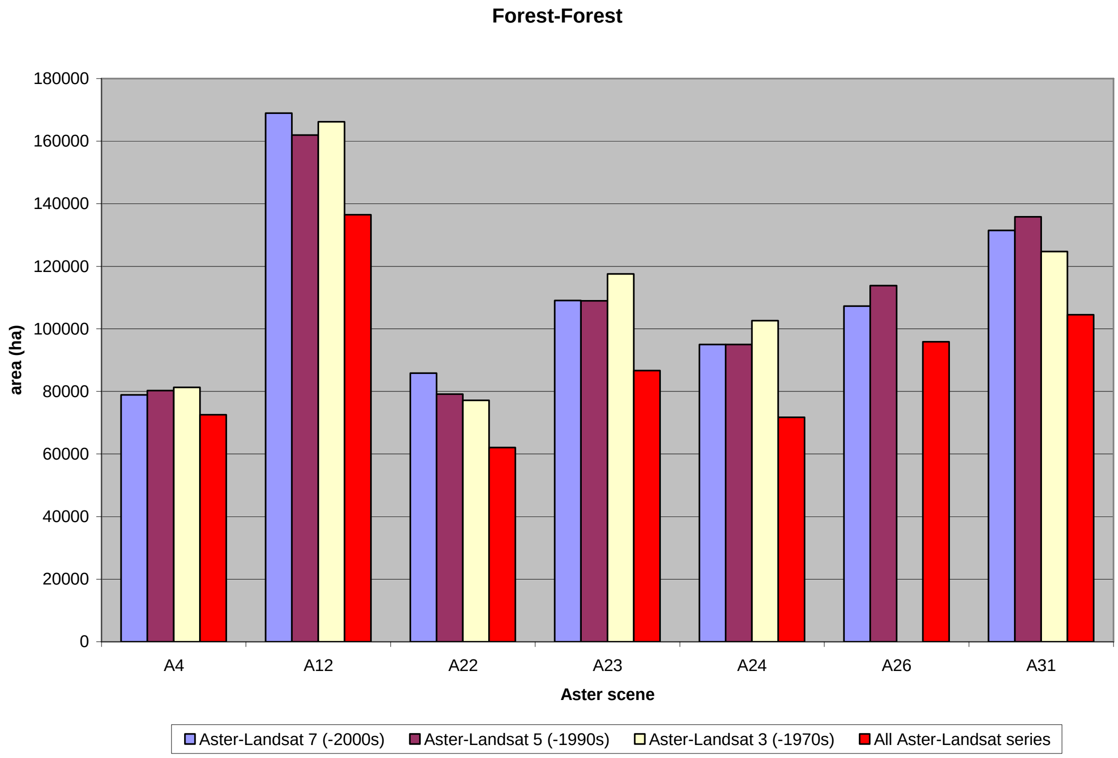
Indeed, one by-product of interest which could be derived from a land change detection exercise using this method, is a kind of "updated" forest cover (-2007 in this case). Indeed, whatever has been classified as F-F and comes up as such in our land change dataset, is logically what ***was*** forest in the earlier date and still ***is*** forest on the latter date. In this respect, the expectation is therefore that the "forest cover" obtained from each three time-series for a single scene should, to a fair degree, be of similar proportion and position across. These area figures for each scene are tabulated below.

Aster #	**Forest-Forest (ha)**		
	2007 (- 2000s)	**2007 (- 1990s)**	**2007 (– 1970s)**
A4	78693	80244	81284
A12	168952	161934	166217
A22	85835	79175	77193
A23	109068	109001	117595
A24	95018	94985	102674
A26	107300	113863	-
A31	131508	135814	124726

These area figures for each scene are represented in the chart below.



The difference in size (regardless of spatial position) may not look that important when comparing one time-series to another, for each Aster scene. However when we push that logic further and assume that the "forest cover" (F-F class) obtained from **all** three time-series should still, to a fair degree, be of similar proportion and location across, that is no longer the case, as the chart below illustrates.



That is a disappointing finding, although somewhat expected: by taking this comparative route, it exposed us to the major risk (and flaw) inherent to the post-classification method, as explained earlier: the multiplications of misclassifications and aggregations of errors across time-series. This therefore suggests that there is not a fair chance to agree on a definite "forest cover 2007" area, to which the deforested areas as classified and presented above, could be added to reconstruct earlier dates forest covers and derive deforestation rate and forest loss.

These problems of classification, therefore throw into question the entire output, including the suggested deforested areas. If a quantitative analysis of deforestation is therefore highly doubtful, a spatial analysis of the traces of deforestation as detected however could yield another by-product: the identification of potential "hotspots" of deforestation, if/where the F-NF class is present in all three time-series. When displaying those spots on screen, inspecting those visually, discarding clumps of pixels that still remains from "salt-and-pepper" effect, and concentrating on areas where traces of F-NF class consistently appear throughout the various time-series outputs, there are a few areas which indeed grab the attention as particularly standing out. The districts were those deforestation spots fall in are displayed in Fig. 4a,b for each half of our AoI. Should the security situation allows, they may constitute priority areas to be checked on the ground, verify current land cover (supposedly, NF) and check the historical trend (previously F).

Fig. 4a Districts with traces of deforestation detected (Northern Area)

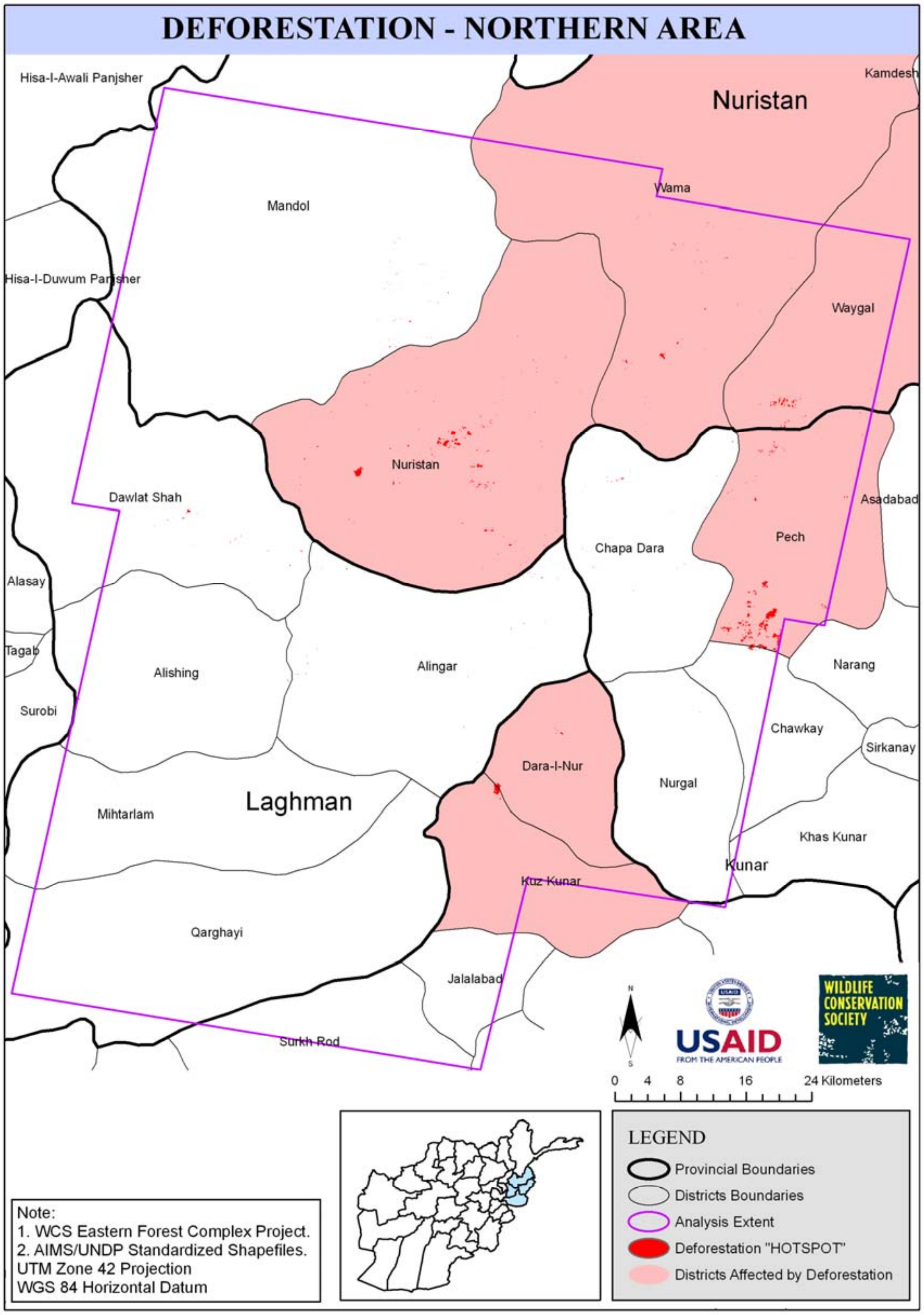
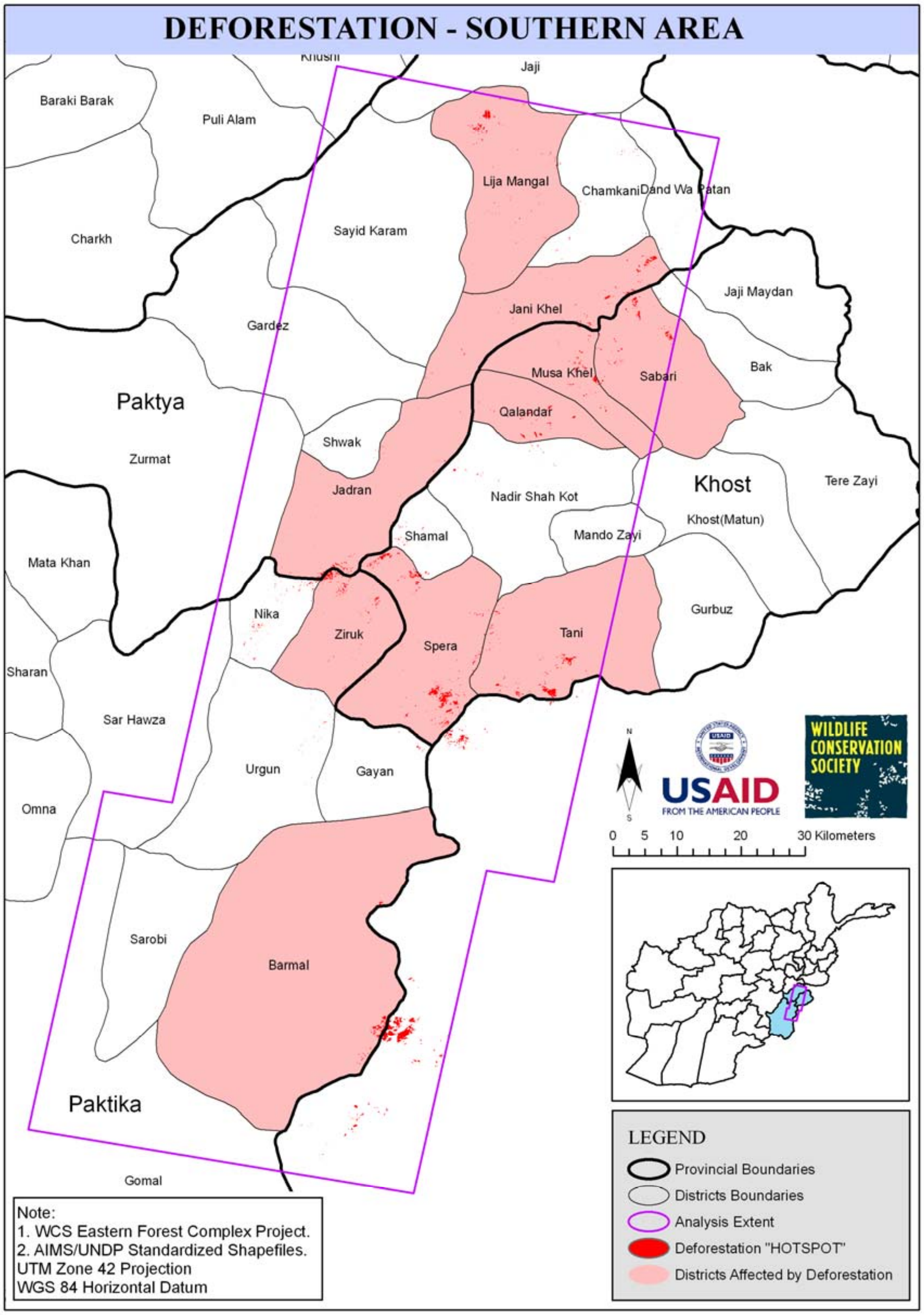


Fig. 4b Districts with traces of deforestation detected (Southern Area)



Also, bearing in mind the limitations of the post-classification type of analysis as described above, another by-product could be the construction of an updated forest cover -2007, based on the different time-series, with a two-fold approach:

1. the Intersection of Outputs, hereafter the "**AND**" option, which retains only the F-F pixels present in **all three** time-series, which essentially means that forest has been visually detected on all four times (-2007s, -2000s, -1990s, 1970s). The likelihood that forest has been present and is still present must be high.

2. the Union of Outputs, hereafter the "**OR**" option, which considers all F-F pixels as they have been detected in **at least one** time-series, which means that forest has been visually detected on minimum two times (out of max. four). The likelihood that forest has been present and is still present is obviously lower than the "AND" option; however it may still be higher than if classifying a single -2007s scene - in effect, earlier dates scenes have been used as ancillary data to help making decision on forest class attribution for 2007.

The variations in forested areas considering the "AND" and "OR" options for each scene are charted below. These forested areas are mapped on Fig. 5a,b for each subset **(**North and South) respectively.

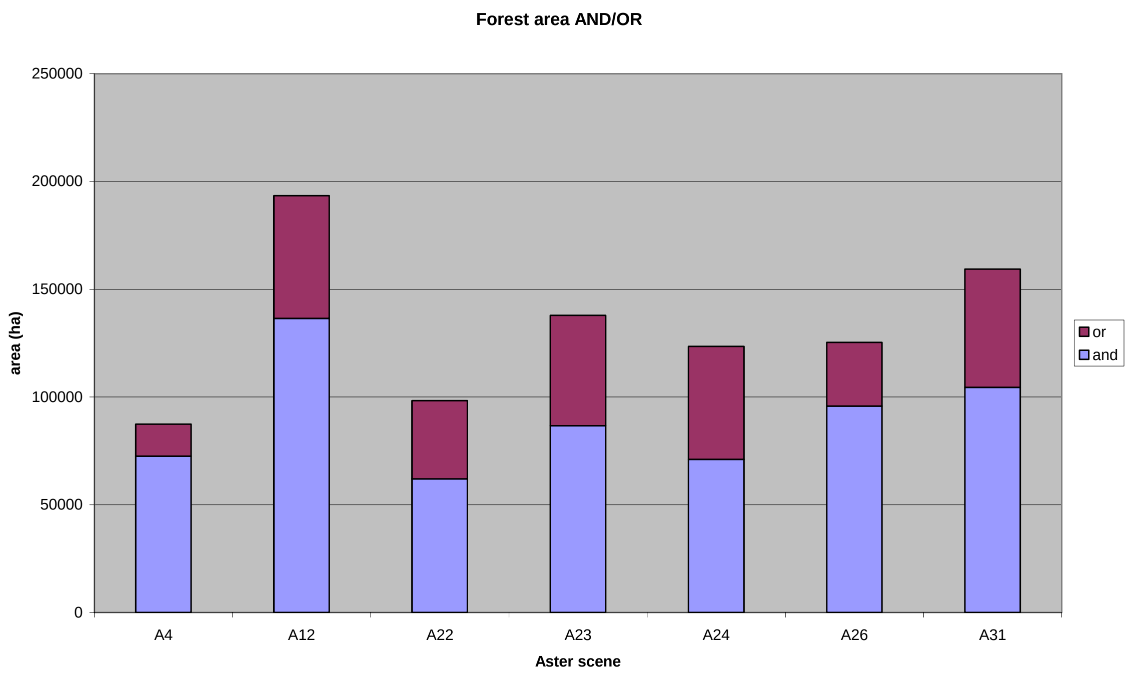


Fig. 5a Forest patches (Northern Area)

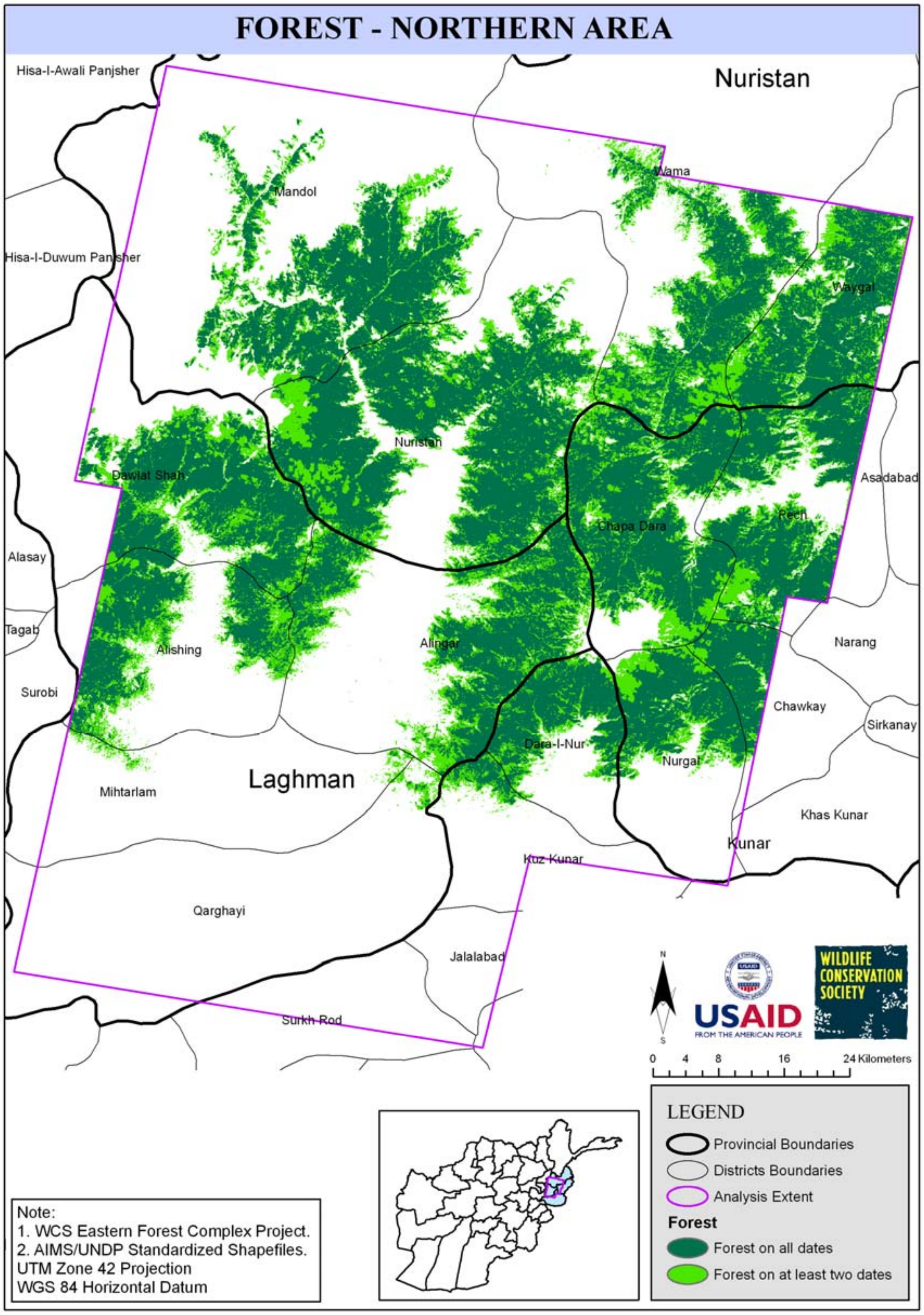
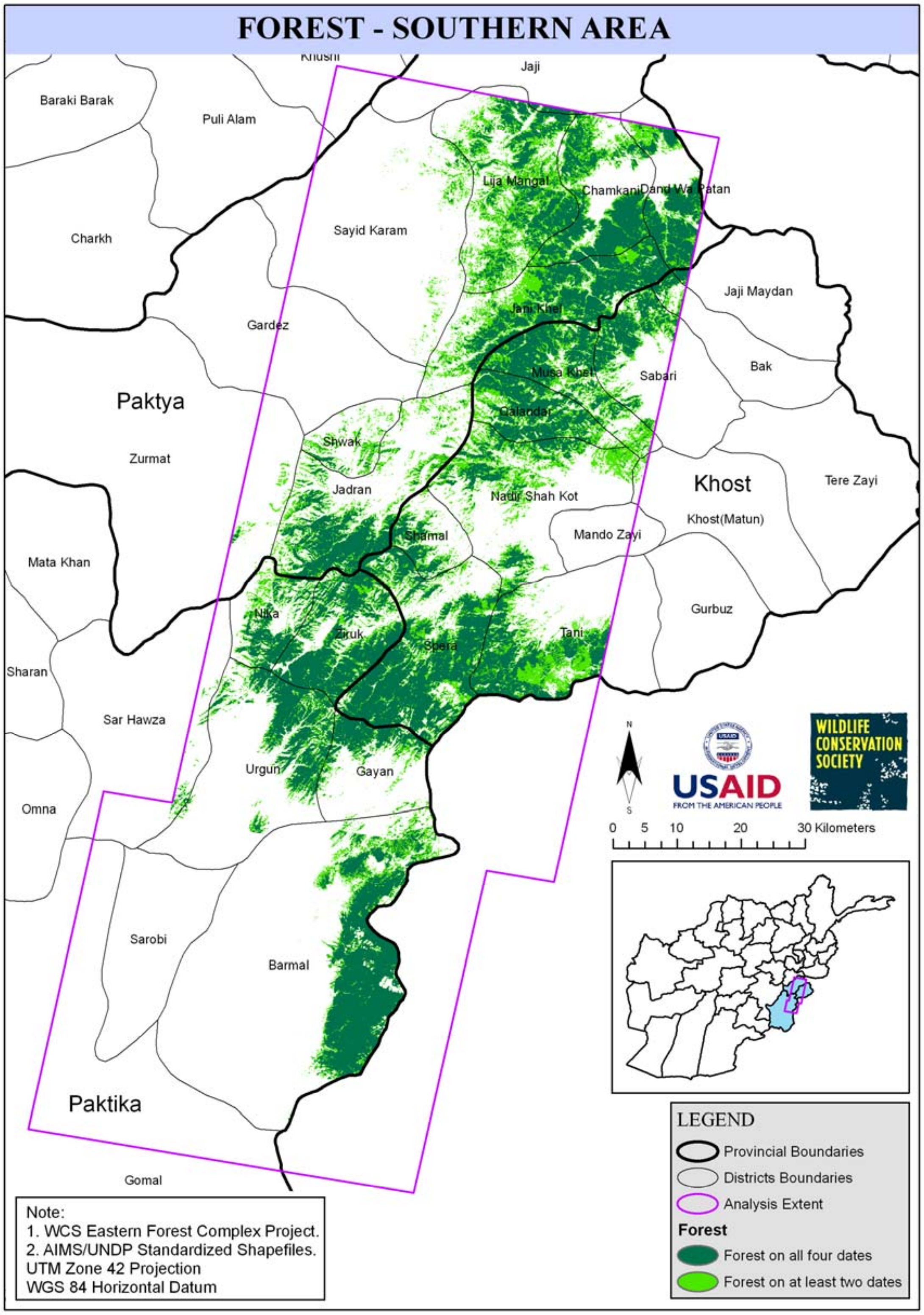


Fig. 5b Forest patches (Southern Area)



Accuracy assessment

As said, a proper set of point data collected across the AoI for the purpose not only of training site but also accuracy assessment was not available. Hence, there is not such thing as a way to assess the accuracy of our first product, the supposed "deforested areas", or rather what we would call "potential deforestation hotspots". As for the second product, an updated forest cover, we used the points collected in the field by the Nuristan Wildlife Survey team, as explained above. As almost the entire set of points was within the extent of the Aster scene A31, we did run an accuracy assessment of the forest cover output for that scene only. Depending which output we treat, the "AND" vs. the "OR" output, the result of accuracy assessment varies significantly.

For A31 forest cover -2007 "OR" product, the accuracy assessment results are as follow:

Accuracy	Forest
Omission Error	**11.8**
Producer's accuracy	**88.2**
Commission Error	**0.0**
User's accuracy	**100.0**

Given only a single class is envisaged ("Forest"), the Overall Accuracy is indeed **88.2 %**, which is well above the minimum of 80 % accuracy generally seen as the minimum level for acceptance. If split into forest sub-classes, it scores extremely high for the "Conifer" points (O.A = 93 % for 576 pts), while fairly high for the "Oak" points (87 % for 822 pts);

For A31 forest cover -2007 "AND" product, the accuracy assessment results are as follow:

Accuracy	Forest
Omission Error	**35.4**
Producer's accuracy	**64.6**
Commission Error	**0.0**
User's accuracy	**100.0**

Given only a single class is envisaged ("Forest"), the Overall Accuracy is indeed **64.6 %**, which is well below the minimum of 80 % accuracy generally seen as the minimum level for acceptance. If split into forest types, there is not a single sub-class which would fare well enough, as all score below 70 %.

DISCUSSION

The ambition of the project, the intensity of the process and the scale of the means implied, have steadily masked a crude reality: any scientifically-sound remote sensing initiative can hardly succeed if there is not a strong presence in the area of interest, a wide knowledge of the features, patterns and trends of the landscape, and a dedicated effort to collect as much ground truthing points as effectively possible, critical inputs to both pre- (for training sites) and post- (for accuracy assessment) classification. For multiple reasons hinted above, this project could not get the baseline data (F-NF points) it would have needed in order not only to find but also to substantiate any findings regarding current forest lost, deforestation trend over time, and remaining forest cover + largest patches. In the absence of this crucial element, whatever sophistication is brought in and whatever effort is put in, such exercise brings at the end little validity.

Deforestation

In our case, the exercise could not reveal any blatant evidence of large-scale deforestation. That goes against the general perception in the country that the Eastern Forest Complex is being increasingly depleted of its timber stock, corroborated by the UNOSAT study (2003) which estimated the reduction in forest cover since the 70s for the three provinces with important forest resources (Nuristan, Kunar, and Nangarhar) in a staggering 20-45 % range (UNEP/UNOSAT 2003); interestingly enough, those results happened to match commonly perceived rates of deforestation. Our fragments of results however go well with anecdotic reports of non-existence of large-scale forest clearance in WCS Afghanistan's study area in central Nuristan (Dr. Stephane Ostrowski, pers. comm.); while the Program's Timber Trade study, also unlike the expectations, did not find evidence of noticeable timber volume from the most important forested provinces of Nuristan and Kunar; only two eastern provinces, Paktia and Khost, did figure prominently in the estimates of Kabul timber trade volumes (WCS 2008).

It remains however, that those three elements internal in WCS do not constitute evidences strong enough to be able to state a definitive opinion on the current status of the EFC. In particular for this analysis, the few traces of forest loss that we may have detected should remain labeled with question mark and at best considered as indicative of a phenomenon which may well (but may not) have happened on those spots. *If* deforestation has indeed taken place, it is even not clearly understood what kind of "forest loss" happened: *blanket removal* of all standing trees (our assumption, from "Forest" to "Non-Forest"); or rather a more subtle forest *degradation*, plainly undetectable through limited remote-sensing analysis. Hence, the current land cover present on the ground for those spots that we detected (supposedly, "Non-Forest"), remains hypothetical and unchecked, given the security in the region makes it a near-impossible venture for the moment. Meanwhile, the past land cover status for those spots as detected (supposedly, "Forest"), could hardly be verified through the use of historical maps, as there are likely substantial differences in mapping methods (*e.g.*, image source, image classification, seasonality factor, etc…) used, let alone in the very definition of what is/was *forest*. Therefore, facts findings missions on the past and present status of local forest resources are needed. Should the security improve in the region, those spots could constitute a batch of first "hotspots" for field enquiry and ground checking.

Forest cover

An updated forest cover, as an unexpected by-product of this exercise essentially targeting to get figures of forest loss and deforestation rate, is a more likeable output. As we were so focused in detecting Forest vs. Non-Forest status over multiple time-series, we tried to maximize that effort by working on individual, original Aster scenes carefully selected across the EFC in order to find and document evidence of forest loss and spatial and temporal patterns of deforestation. This labor-intensive approach, although still in a testing mode, has certainly hindered an additional benefit that we may have wanted to focus on at some stage: to get a whole EFC-wide forest cover update instead. As explained, one can always derive a later date forest cover from a change detection exercise, as we did. The limitations here is that the forest cover as obtained is still in "pieces" (made of individual Aster scene), which will require some additional edge-matching work, while just over half of the EFC has been analyzed so far.

The two analysis outputs obtained for each scene, the "AND" and the "OR" products, form certainly a good basis. As the limited accuracy assessment did show (for a single scene only), the classification's overall accuracy of the "OR" output (88.2 %) is rather satisfying; it even reached 93 % when using Conifer forests points (576 pts) alone. Given the high number of points used (1,509 pts) and the substantial proportion of the scene covered by those points (20-25 % of the scene, after area extrapolation), this is a solid mark of confidence.
That confidence falls quite sharply when the "AND" output is assessed for accuracy, with an overall score lower than 70 %, deemed unacceptable. It is a great demonstration of the flaws inherent to the post-classification method (that we are finally applying here when overlaying the three time-series), where a series of classification outputs are combined together… with their intrinsic classification errors. In our case, it seems that the "AND" output is far too conservative, missing out a substantial proportion of the forested area[1]. A forester would wonder what kind of forest structure (variations in canopy density) or forest type (variations in forest composition) is there on the ground to be systematically detectable in all four images - and which one is being left out. Meanwhile, the discrepancies between the different time-series outputs for a single scene, even though classified "semi"-independently (by recycling training sites from one to another), show at length the limitations of data and method that we faced, and that remote-sensing is anything but a rock-solid science without the crucially important step of validation through ground-checking and accuracy assessment.

Limitations in the datasets and the method

There are a number of potentially limiting factors from the variables that are inter-acting in the process of creating a change detection map. These variables are obviously not all equal in effects.

[1] Incidentally, it seems still to be far larger than the forest cover/patches obtained by UNOSAT for that area

In practice, some of them were well addressed.

- The land cover classes were reduced to fewest number of classes possible, and clearly defined : Forest, Non-Forest, Agriculture, Barren and Water.
- The entire series of satellite images were analyzed by a single operator, using a set protocol.
- Instead of comparing two classified forest covers (the post-classification method), we did measure one-time series forest cover change directly (applying the multi-layer classification method).
- Given it was still needed to compare multiple time-series together, we sought to minimize the risks of post-classification between those time-series by recycling the set of training sites of one time-series (after check) to the following ones.

While those variables above were kept in check, several others remained beyond control.

- Given it was impossible to use similar imagery when conducting land cover change over such a long time period (four decades), we had to deal with different dataset types for each time-period; each data having its own specifics and limitations, as described earlier.
- The data normalization, in terms of geometry (image-to-image registration) and radiometry (atmospheric corrections), proved to be difficult for the former (due to the terrain), and simply impossible for the latter. In particular, registration errors can be significant when comparing dissimilar datasets.
- The variation in solar illumination in such mountainous terrain was intense, and therefore challenging at best[2].
- The variation in seasonality was another potentially important factor, given the differences in acquisition dates of our collection.
- Likely some forest types on the ground, possibly from wide open forest patches to scattered trees, constituted another problem for the detection.
- The fact that we were considering an automated approach throughout the three time-periods, without editing the previous change images to update land change information (e.g., by using visual methods primarily), exposed us to the risk inherent to post-classification overlay to derive forest loss/deforestation results.
- The sensitivity of the Dtree/See5 algorithm in terms of misclassification errors in this kind of landscape, especially for areas with haze and/or of high topographic complexity, has never been tested.
- Lack of proper accuracy assessment to validate results.

[2] Even Landsat data, well suited for monitoring change, is reportedly problematic for areas where terrain variation is significant.

CONCLUSION

To obtain an update of forest cover and change in the Eastern Forest Complex was a legitimate initiative, as an integral part of a properly designed biodiversity conservation program in Afghanistan. The project was ambitious, the process intense, and the scale of the means large. By contrast, this study delivers unsubstantiated results likely to be judged as below the initial expectations. Assuming there was deforestation, nothing will be known of which period saw the greatest forest loss, where the greatest forest loss occurred, is there such thing as a deforestation path "on the move", what are the impacts of villages, roads, the border etc… Indeed, this study has avoided the pitfalls which sometimes make other similar studies gone bad. Facing severe obstacles and limitations, not least a lack of sound knowledge of the landscape and the complete absence of reliable field data (both past and present) for classification and validation, it demonstrated enough a wisdom by scaling the scope down to a testing mode - instead of running it all the way without discernment and with short-comings, to be hidden behind "nice" figures and fancy maps. Hence, if there is not any reliable figure of forest loss and spatial/temporal trends in deforestation to be extracted from this study, there are a few positive outputs to be highlighted. WCS Afghanistan Program is now custodian of what is by far the most comprehensive collection of imageries for the Eastern Forest Complex to be found anywhere in Afghanistan. This is a precious asset which needs to be maintained and, should the circumstances arise, supplemented/shared. Additional datasets said to exist, such as a higher resolution DEM (30 meters) and a set of high resolution aerial photos, should be incorporated for future analysis. The first step in building a sound field-based ground-truth dataset has begun; should the security situation improves, it should be further developed and enhanced. Through this exercise, the Program has been intensely exposed to the techniques, joys and troubles, tricks and tips of a remote-sensing based land cover change detection; should the suggestion below calling for an updated forest cover be followed, it should foster the current in-house capacities, a rare commodity in Afghanistan.

The way forward

While estimating forest loss and deforestation trends over time and space is probably no longer a field of activity to be considered as a priority, exploiting the best of the current collection of images, together with a dedicated ground-truthing effort, should remain high on the Program's Eastern Forest Complex agenda. Holding a mosaic of up-to-date (2006-2007) medium resolution imageries (Aster, Spot) of decent quality that is nowhere else to be found in Afghanistan, there could still be a workable way to obtain a EFC-wide forest cover update (2007), based on those recent imageries. Following that route, highly valuable information such as "where is the remaining forest cover", "where stand the largest forest patches", and "where are potential corridors in between those to work on", could still be tentatively obtained through the most suitable method of choice. As said, oftentimes "*the state of the practice is often more appropriate than the state of the art*". Equipped with a solid and representative set of data points, a renewed effort of sound automated classification of a mosaic of imageries covering the entire EFC could be envisaged. If not enough data points (for training sites) are available, still it could then be envisaged to "backtrack" somewhat and re-envisage a more manual-oriented approach: through on-screen visualization, display and editing of either the land cover dataset of reference "FAO93" or any other released (USGS 2007), after visual assessment, against the original, individual, mid-resolution Aster and Spot scenes. Often discarded as too simplistic, this method may actually deliver a valuable product from the existing inputs currently in WCS Afghanistan custody, and with limited additional efforts. Any such output however will invariably remains in need to be checked for accuracy against field data points.

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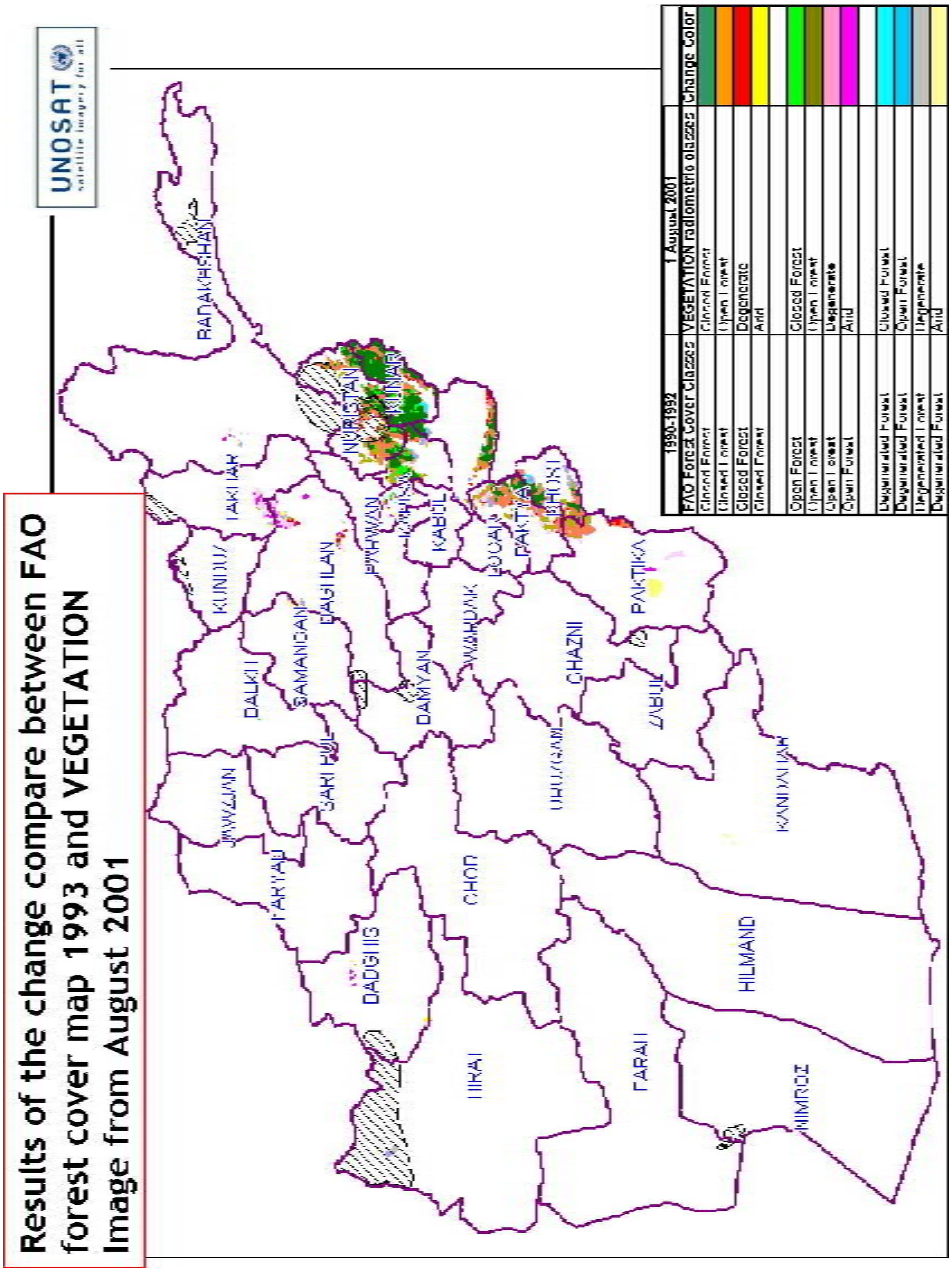
APPENDICES

Appendix 1 Forest cover change (2001-1993) for the Eastern Forest Complex (UNEP/UNOSAT 2003)



Appendix 2 Forest cover change (2002-1977) for Nuristan, Kunar and Nangarhar provinces (UNEP/UNOSAT 2003)

UNOSAT service report no. 3/2003- Post Conl.f Assessm., Afghanistan

Forest cover change in Nuristan, Kunar and Nangarhar provinces

UNOSAT's satellite image analyses revealed a significant drop in forest cover in Afghanistan. As an example, forest cover in the three eastern provinces of Nuristan, Kunar and Nangarhar was reduced by 43%, 24% and 22% respectively, during the last 15 years. In other provinces the reduction of forest cover is even higher. This reduction is due to several factors, including fuel wood consumption, livestock grazing and armed conflict. Figure 4 clearly illustrates the significant reduction in forest cover in what is generally thought to be one of the most forested regions of Afghanistan.

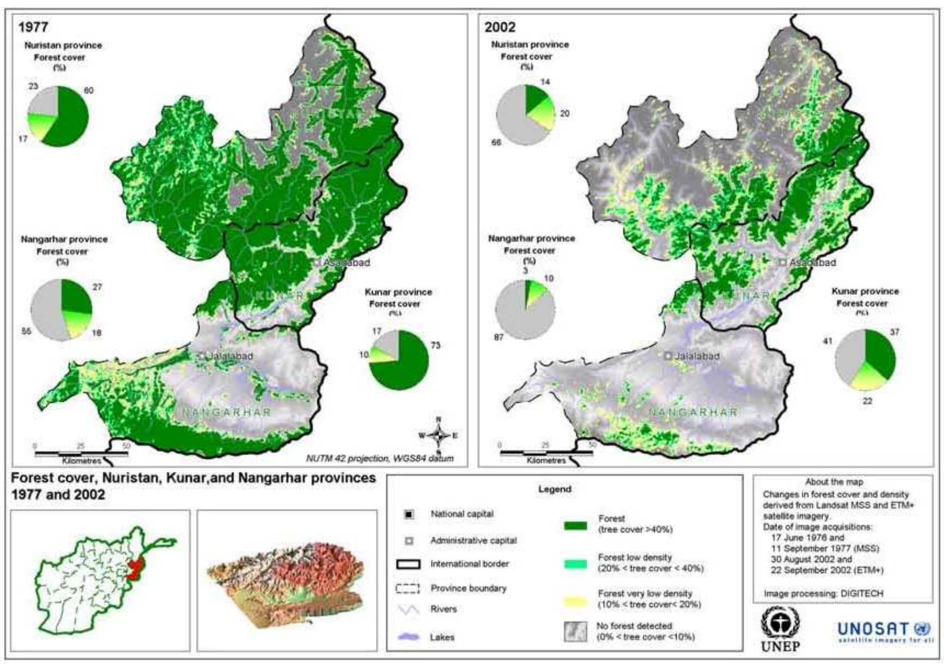
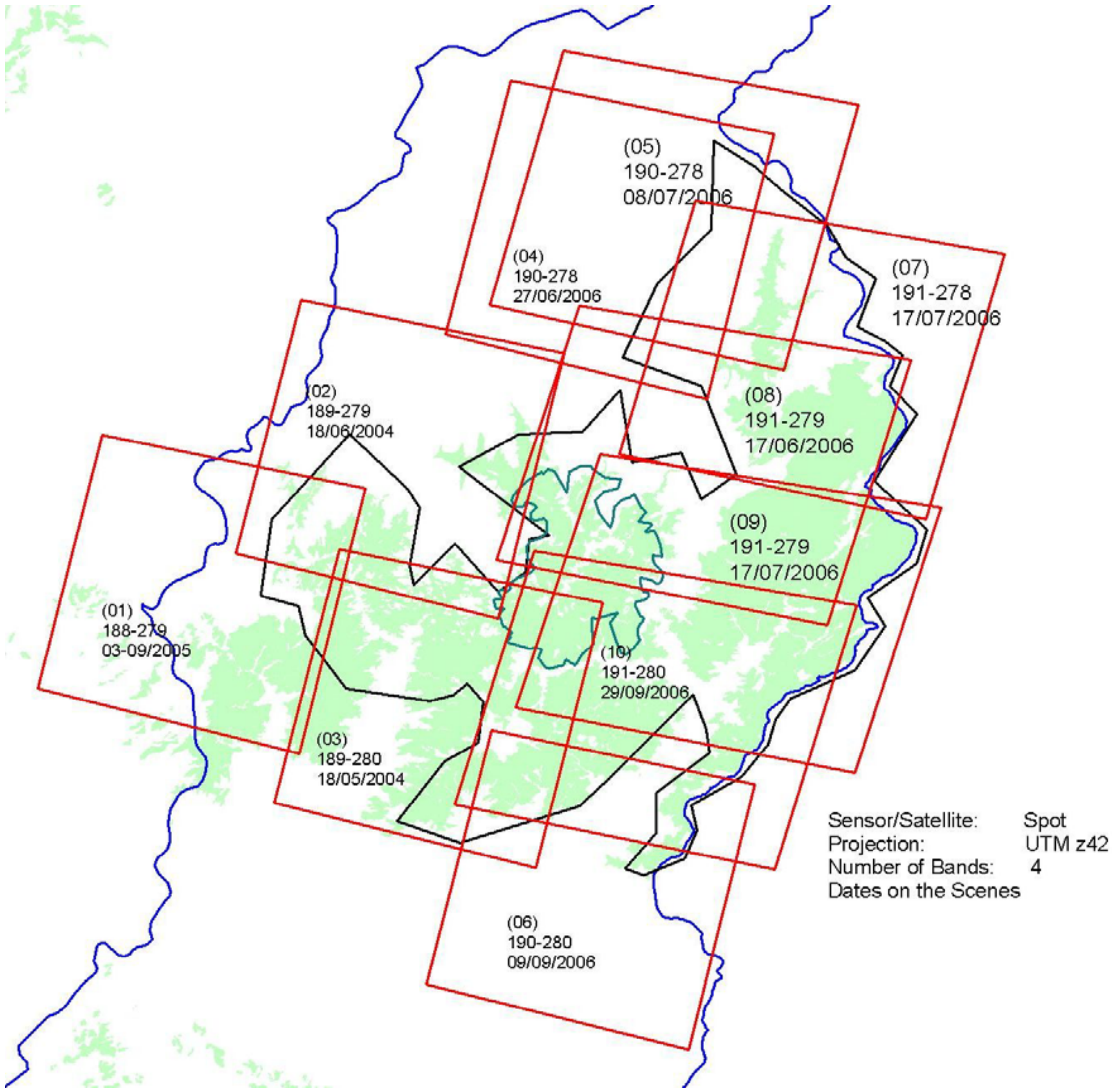
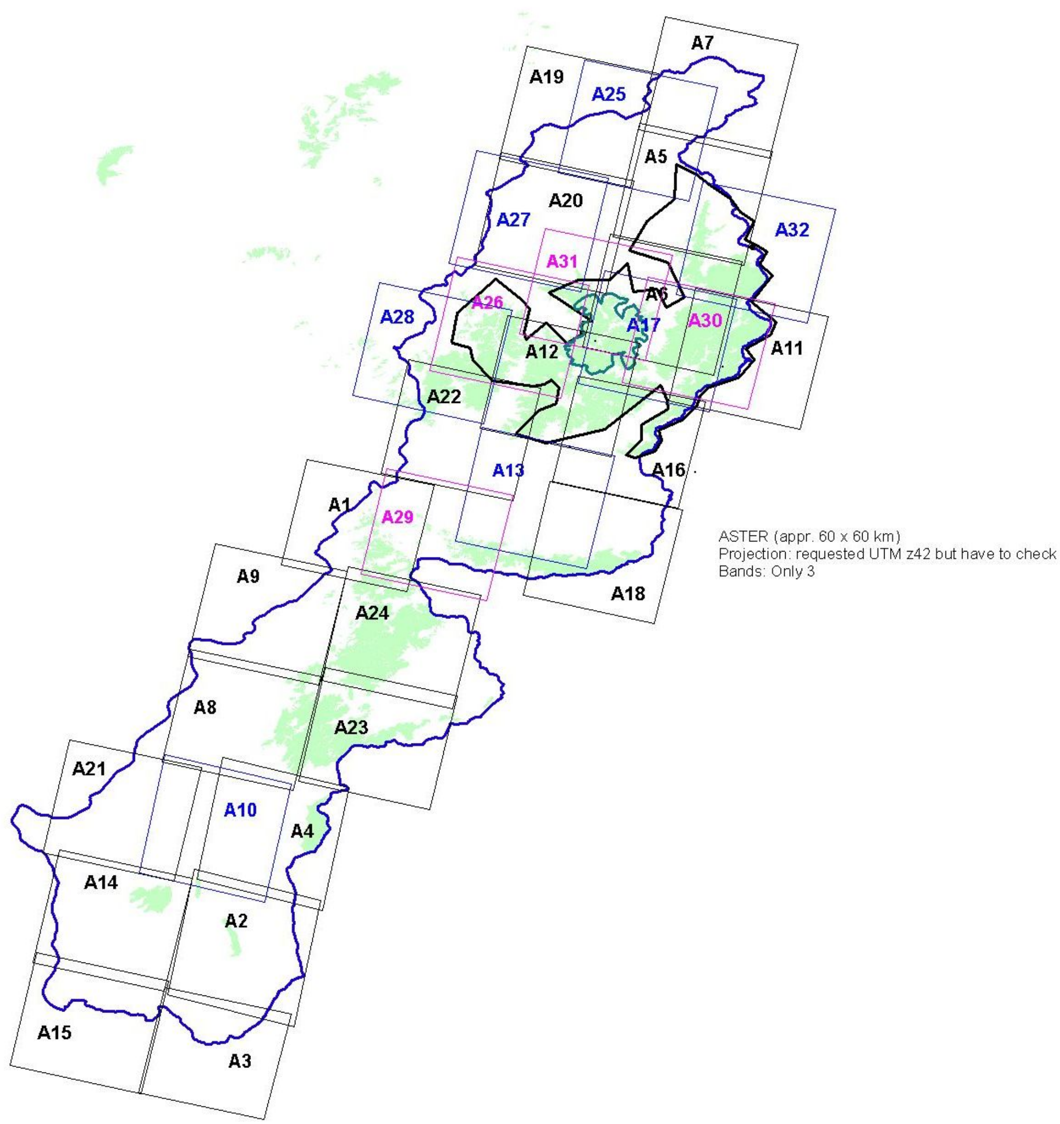


Figure 4: Changes in forest cover derived from satellite imagery.

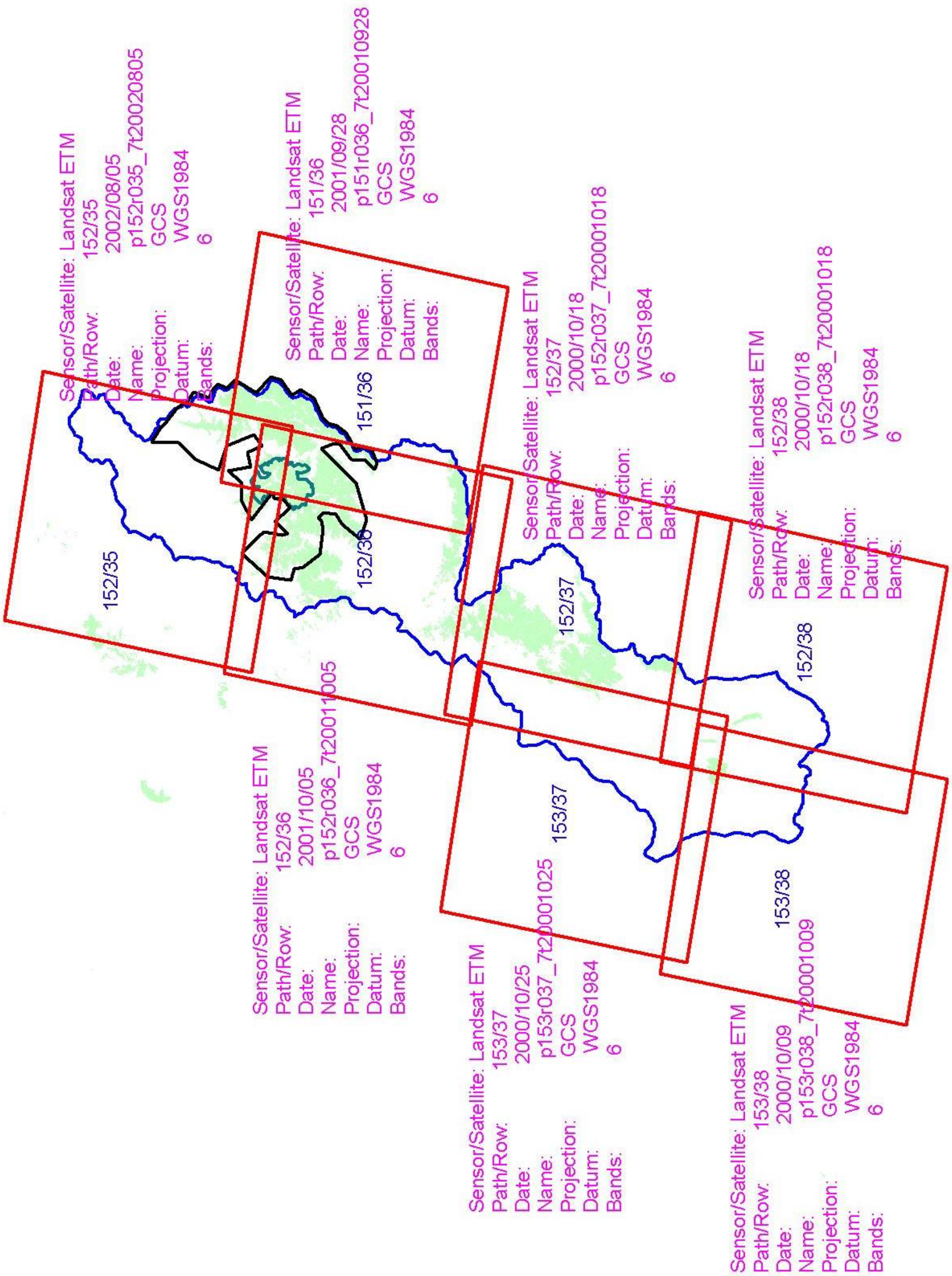
Appendix 3a Spot coverage (2004-2006)



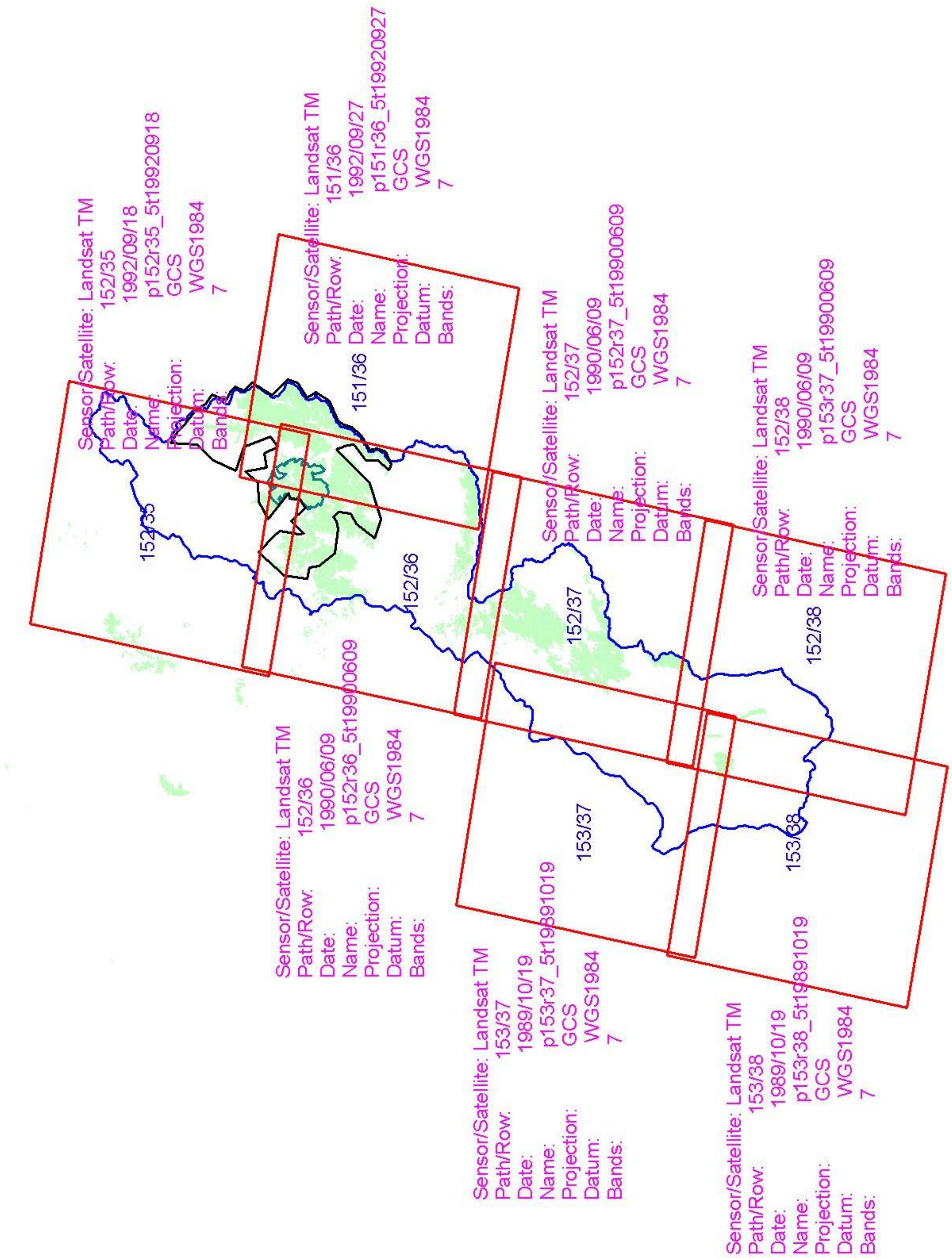
Appendix 3b Aster coverage (2004-2007)



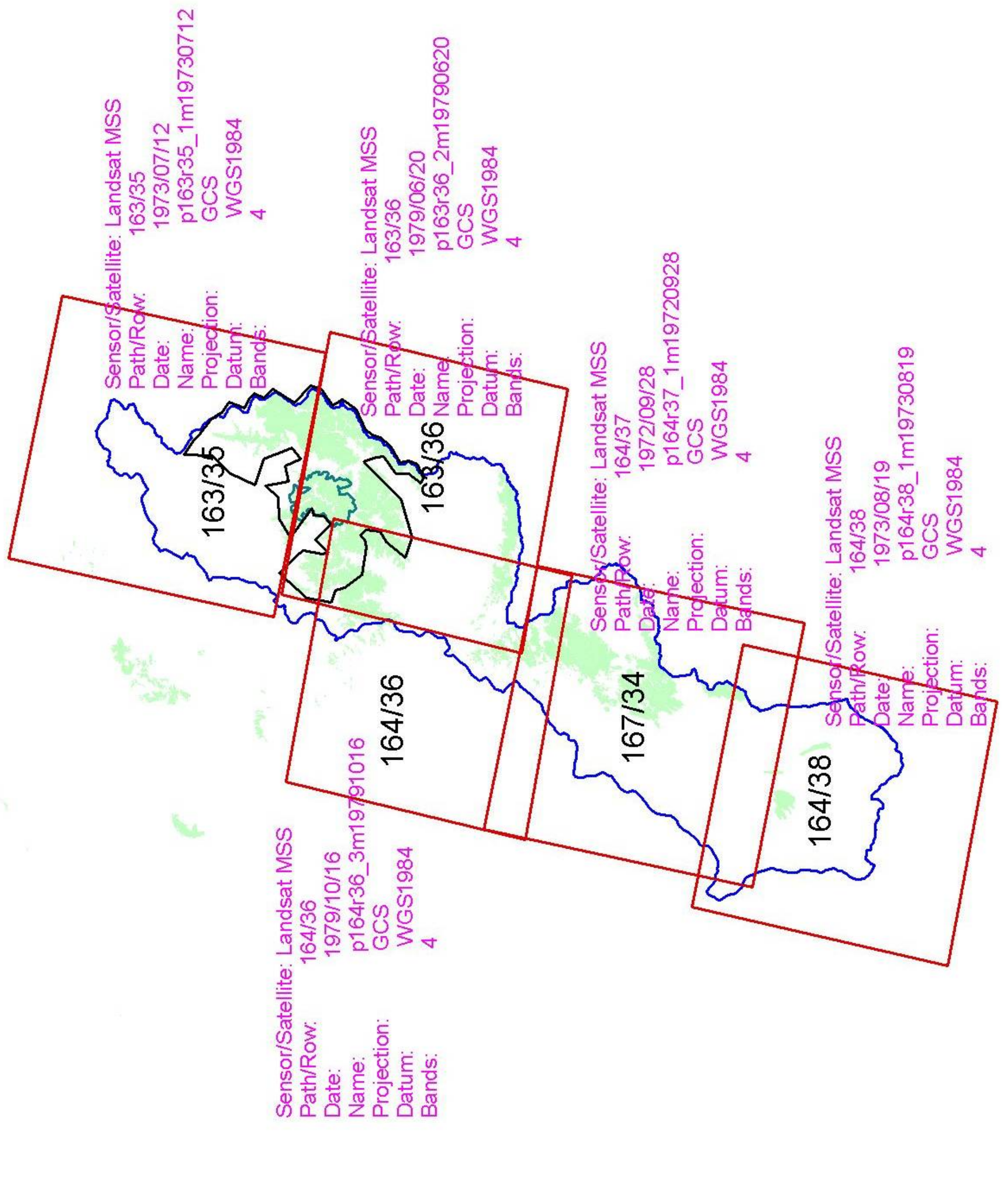
Appendix 3c <u>Landsat ETM coverage (2000-2002)</u>



Appendix 3d Landsat TM coverage (1989-1992)



Appendix 3e Landsat MSS coverage (1972-1979)



Appendix 4 MLC vs. Dtree (CI-CABS 2006)

C. MLC vs. Decision Trees

You might now be asking yourself, which do I use, MLC or decision tree? It's helpful to have experience with both and to compare for yourself. Previous research has found that decision tree classifiers produce approximately 10% more accurate classifications than the Maximum Likelihood classifier. In addition, the decision trees are easier to run and faster in most cases. The decision tree will produce much better results after just one or two iterations. For example, in Fig.11, you will see two classifications from the same region in Sumatra, Indonesia. The classification on the left is the MLC result after 4 iterations while the classification on the right is the decision tree after 2 iterations. Notice that the decision tree is much 'cleaner' after just two iterations than the MLC after four iterations.

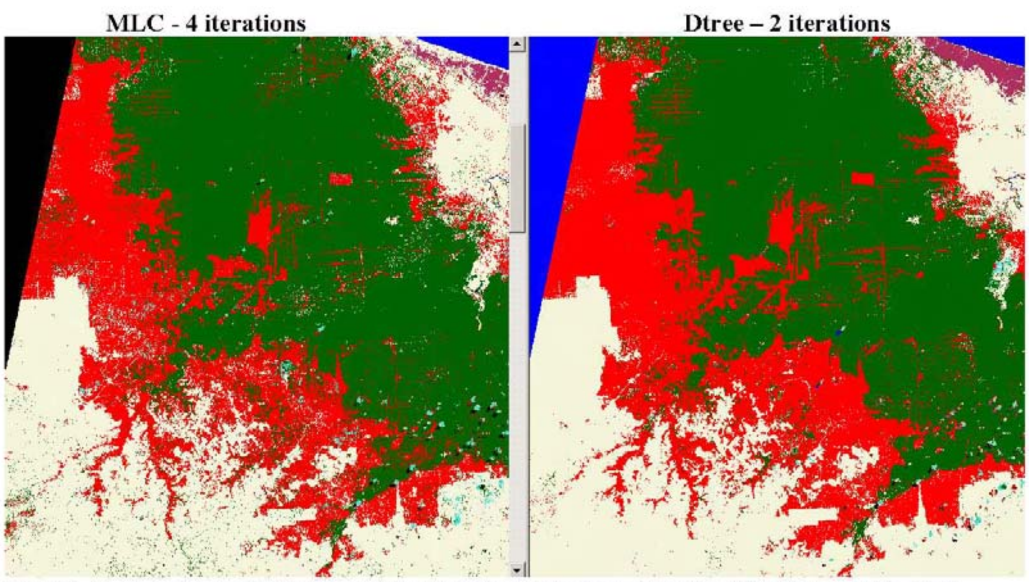


Fig. 11. Comparison of Maximum Likelihood and decision tree classification results. Red indicates deforestation, green is forest, tan is nonforest, and light blue represents clouds.

Fig. 12 shows a similar result in another region of Sumatra. This region is difficult due to haze in the imagery. The MLC classification after two iterations still contains many errors and misclassifications. There is a lot of nonforest that is being classes as forest, and also cloud that should be classified as nonforest. The decision tree result, on the other hand, looks much nicer after the same number of iterations and produces a nice result despite the haze. This classification is not yet complete, but the analyst should be able to finish the classification in much less time using the decision tree approach.

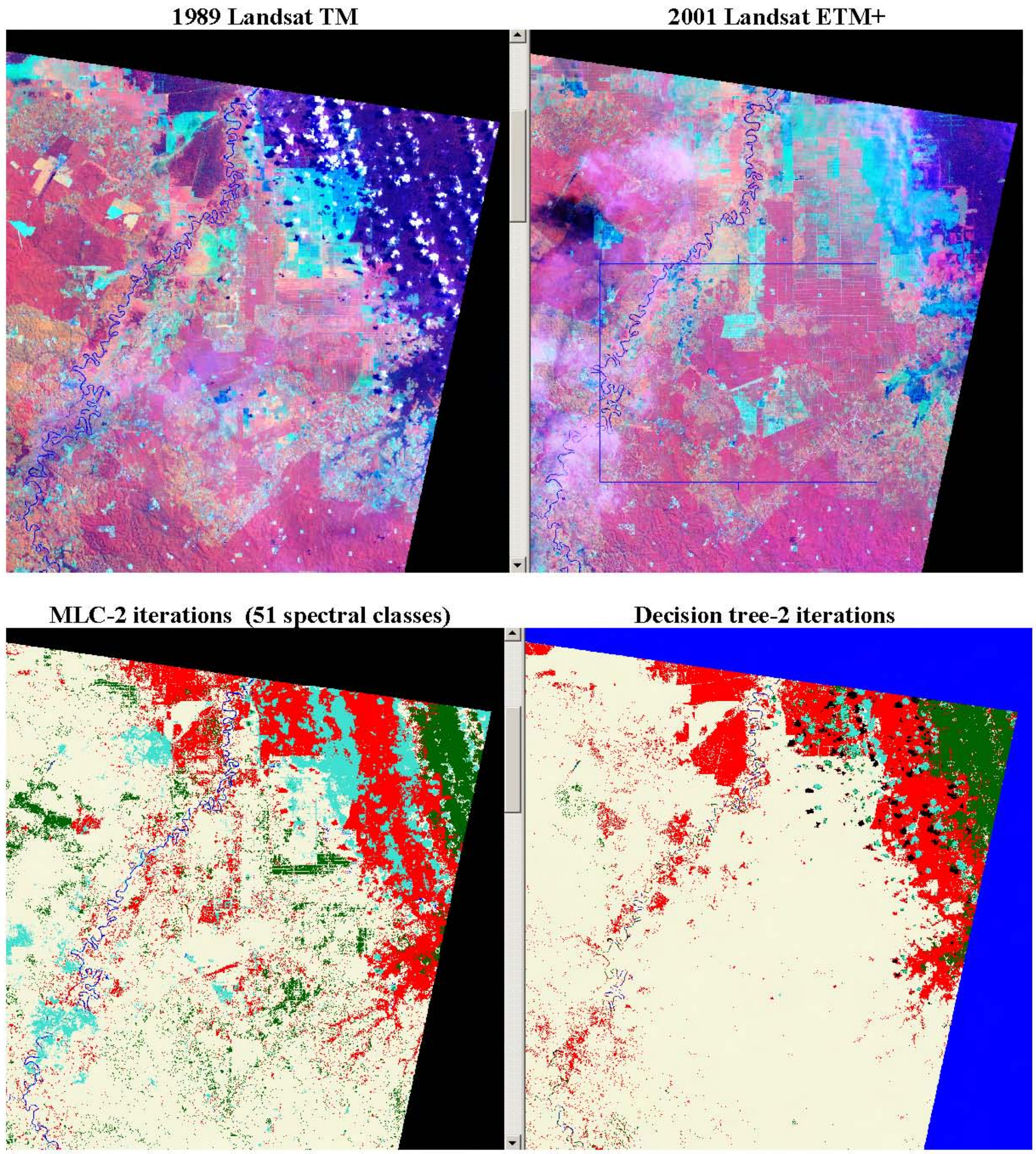


Fig. 12. Landsat 5 and 7 data from Sumatra, showing a comparison of an MLC and decision tree classification, after two iterations.